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DISASTER WARNING SYSTEM: SATELLITE FEASIBILITY AND COMPARISON WITH TERRESTRIAL SYSTEMS

VOLUME II - FINAL REPORT

by J. H. Spoor, W. H. Hodge, M. J. Fluk, and T. F. Bamford

Aerospace Systems Operation
of

COMPUTER SCIENCES CORPORATION

(NASA-CR-134622-Vol-2) DISASTER WARNING
SYSTEM: SATELLITE FEASIBILITY AND
COMPARISON WITH TERRESTRIAL SYSTEMS. VOLUME
2: FINAL REPORT (Computer Sciences Corp.)
196 p HC \$7.50

N76-28269

Unclas

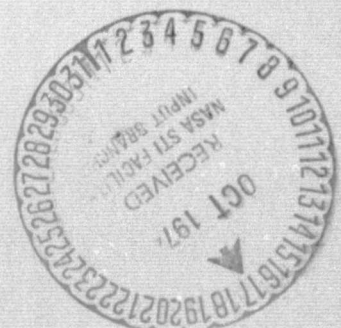
CSSL 17B G3/17 47395

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research Center

Contract NAS 3-17795



(NASA-CR-134622-Vol-2) DISASTER WARNING
SYSTEM: SATELLITE FEASIBILITY AND
COMPARISON WITH TERRESTRIAL SYSTEMS.
VOLUME 2: (Computer Sciences Corp.)
186 p LIMIT GOVT. + CONTR. CSSL 17B F3/32 02902
Unclas

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1. Report No. NASA CR-134622		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Disaster Warning System: Satellite Feasibility and Comparison with Terrestrial Systems Volume II - Final Report				5. Report Date September 1974	
				6. Performing Organization Code	
7. Author(s) John H. Spoor, W. H. Hodge, M. J. Fluk, and T. F. Bamford				8. Performing Organization Report No. R-3015-3-1	
9. Performing Organization Name and Address Computer Sciences Corporation Falls Church, Virginia 22046				10. Work Unit No.	
				11. Contract or Grant No. NAS 3-17795	
12. Sponsoring Agency Name and Address National Aeronautics & Space Administration Washington, D. C. 20546				13. Type of Report and Period Covered Contractor Report	
				14. Sponsoring Agency Code	
15. Supplementary Notes Project Manager. James R. Ramler, Space Flight Systems Study Office, NASA Lewis Research Center, Cleveland, Ohio					
16. Abstract The Disaster Warning System (DWS) is a conceptual system which will provide the National Weather Service (NWS) with communication services in the 1980s to help minimize losses caused by natural disasters. The object of this study is a comparative analysis between a terrestrial DWS and a satellite DWS. Baseline systems satisfying the NOAA requirements were synthesized in sufficient detail so that a comparison could be made in terms of performance and cost. The cost of both baseline systems is dominated by the disaster warning and spotter reporting functions. An effort was undertaken to reduce system cost through lower-capacity alternative systems generated by modifying the baseline systems. By reducing the number of required channels and modifying the spotter reporting techniques, alternative satellite systems were synthesized. A terrestrial alternative with the coverage reduced to an estimated 95 percent of the population was considered. Volume I - Executive Summary Volume II - Final Report Volume III - Appendices					
17. Key Words (Suggested by Author(s)) Disaster Warning Satellite Broadcasting System Costing			18. Distribution Statement U.S. Government and Contractors Only		
19. Security Classif. (of this report) UNCLASSIFIED		20. Security Classif. (of this page) UNCLASSIFIED		21. No. of Pages 22. Price --	

FOREWORD

This document is Volume II of three volumes prepared for the NASA Lewis Research Center by the Computer Sciences Corporation (CSC) under Contract NAS3-17795. The CSC Project Manager was John H. Spoor. The primary members of the study team were W. H. Hodge, M. J. Fluk, and T. F. Bamford. Study participants included G. Pendleton, W. E. Andrews, P. K. Carlston, and B. F. Adams.

This study was managed by NASA for the National Oceanic and Atmospheric Administration (NOAA) under the technical cognizance of the NASA Project Manager, James R. Ramler, of the Lewis Research Center. The principal NOAA cognizant individual was Jack H. Puerner of the National Environmental Satellite Service. Valuable assistance and guidance from NOAA was provided by Bernard Zavos of the Office of Associate Administrator for Environmental Monitoring and Protection, Sam Grimm of the National Weather Service, Walt Castle of the Office of Policy and Planning, and Vern Zurick of the Environmental Research Laboratories.

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SECTION 1 - SUMMARY

The Disaster Warning System (DWS) is a conceptual system which will provide the National Weather Service (NWS) with communication services in the 1980s to help minimize losses caused by natural disasters. The communication services are grouped into four functions: disaster warnings, spotter reports, data collection, and coordination within the NWS.

The objective of this study is a comparative analysis between a terrestrial DWS and a satellite DWS. Baseline systems satisfying the NOAA requirements were synthesized in sufficient detail so that a comparison could be made in terms of performance and cost including ten years of operation. Prior to synthesizing these systems, an investigation was made of the present and planned NWS structure, operation, and traffic flow relevant to natural disasters. An estimate, based on past data, of the number of warning messages in 1985 was used in a queueing model to obtain expected waiting times as a function of the number of warning channels.

Both the terrestrial and satellite baseline systems essentially satisfy the NOAA DWS requirements. The exceptions are: the terrestrial system does not provide ocean coverage, and the satellite system provides only 5 rather than 50 simultaneous voice channels to the spotters. The total system cost, including 10 years of operation is \$1.00 B for the baseline terrestrial system and the baseline satellite system cost is \$1.62 B in constant 1974 dollars. The home receiver costs are not included; their unit factory costs are \$17.60 and \$31.20 in quantities of one million for the terrestrial and satellite systems, respectively. The cost of both baseline systems is dominated by the disaster warning and spotter reporting functions. The cost drivers for the disaster warning functions are the required number of simultaneous broadcasts for the satellite system and the extensive coverage for the terrestrial system. The major cost driver for the spotter reporting function is the large number (100,000) of transceivers that must be purchased and maintained for ten years; this impacts the satellite system more since it requires a more sophisticated (costly) transceiver.

An effort was undertaken to reduce system cost through lower-capacity, alternative systems generated by modifying the baseline systems. By reducing the number of required channels and modifying the spotter reporting techniques, alternative satellite systems were synthesized with total costs ranging from \$1.32 B to \$0.87 B. A terrestrial alternative with the coverage reduced to an estimated 95 percent of the population was considered; this reduced the total terrestrial system cost to \$0.84 B.

Further investigation of both the terrestrial and satellite systems is required to develop an optimum configuration and more detailed system definition on which to base a final system choice. Of particular importance is a reassessment of the DWS requirements in view of the cost and system performance sensitivities to the requirements.

SECTION 2 - INTRODUCTION

Each year natural disasters exact an enormous toll in lives, economic loss, and human suffering in the United States. These losses result, in part, from deficiencies in our warning and preparedness programs. Several recent studies (References 1, 2, and 3) identify these deficiencies and propose solutions and courses of action. Many of these solutions require initiatives at the Federal level, involving a number of Federal agencies working together in a coordinated program.

The evolving role of the Federal government in coping with natural disasters is exemplified in the comprehensive Disaster Relief Act of 1970. This Act commits the Federal government, on a permanent basis, to major responsibilities in disaster preparedness planning and assistance. In addition, the Act directs that a full and complete investigation and study be conducted to determine what additional improvements could be made to prevent or minimize the loss of life and property due to major disasters.

The National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce has prime responsibility for detecting, predicting, warning, and preparing for natural disasters and has been a leader in utilizing advanced technology to improve their capabilities. As part of its planning for a future natural disaster warning system, NOAA is currently investigating the potential of various terrestrial and satellite communication systems to meet requirements of the 1980's. Such a communication system is designated a Disaster Warning System (DWS). NOAA has determined that the DWS should:

1. Achieve a significant improvement in existing disaster warning systems, the supporting systems for collection of data and reports, and the coordination essential to the preparation of effective warnings.
2. Expand the area covered by existing warning systems while simultaneously developing a highly selective capability to warn specific groups or areas.
3. Provide a single authentic and highly responsive channel between the warning agency and the general public.
4. Fully exploit existing technology and make maximum use of existing facilities of all participating government agencies.
5. Provide a means by which assistance can be given to individuals, communities, and responsible government agencies in implementing natural disaster emergency readiness plans.

The objective of this study was to synthesize and compare an all-terrestrial as well as a satellite warning system to meet the NOAA DWS requirements in the 1980's. For both the terrestrial and satellite systems, baseline systems are synthesized in sufficient detail to enable an assessment of their technical feasibility, performance, and cost. By varying these baseline systems, alternative systems are generated for comparison purposes and to determine sensitivities to various system requirements and major system cost drivers. Whenever appropriate, new technology required to implement portions of these systems is identified.

Prior to the actual synthesis of systems to satisfy the DWS requirements, an investigation was made of the present and planned NWS structure, operation, and traffic flow. Also, the DWS requirements were assessed, and, if necessary, expressed in terms of communication system requirements. One of the more critical requirements is the amount of warning traffic that is expected in the mid 1980's. Using historical warning traffic data supplied by the NWS and results of previous analyses of the data by NOAA and NASA, estimates are made of the expected amount of warning traffic in 1985. Also, a queueing analysis was performed to estimate expected waiting times for the issuance of warning messages as a function of the number of warning messages, number of communication channels available to send the messages, and time required to send the messages.

The communication requirements are combined into four functional requirements: disaster warning, spotter reporting, data collection, and coordination. In the synthesis of the terrestrial and satellite systems, each of the functional requirements are addressed individually and then combined in the total system description. The major functional requirement is the broadcasting of disaster warnings directly to homes. For the terrestrial system this is implemented using terrestrial broadcasting techniques whereas the satellite system requires geosynchronous broadcast satellites utilizing high-power spot beams.

A detailed cost estimate is made for each baseline system, including a 10-year operational phase. During the first 5 years of the operational phase the system will be gradually built up to a fully operational capability. Based upon these estimates, the major cost drivers are obtained and the costs of alternative systems are shown. Schedules for implementing the baseline systems are also shown. From these schedules, funding schedules are generated for both time dependent and constant year dollars.

Satellite configurations (weight, power, cost) were generated using appropriate estimating relationships based upon historical data where feasible. Other satellite system costs including ground terminals, land line interconnects, spotter transceivers, etc. were directly or analogously estimated as appropriate, as were the terrestrial system costs.

This report is presented in three volumes:

Volume I - Executive Summary

Volume II - Final Report

Volume III - Appendices

SECTION 3 - NATIONAL WEATHER SERVICE STRUCTURE AND TRAFFIC FLOW

3.1 INTRODUCTION

The DWS will provide the communications for disaster warning for the NWS. Since the DWS will be a part of the NWS, it must be compatible with other NWS functions and communication systems. A discussion of the present NWS communications systems is given in Appendix A. This section presents a brief summary of the present and planned NWS structure and its traffic flow. Additionally, there are two warning systems under development that may impact the DWS; these will be discussed individually. A new satellite system has also recently been initiated that has a data collection capability specially designed for automatic collection of meteorological data from remote platforms. This satellite system is discussed since it will impact the DWS.

3.2 NWS ORGANIZATION AND OPERATIONS

3.2.1 Present

The NWS, under the NOAA, operates a network of approximately 400 facilities within the 50 states, at 13 overseas stations and on 21 moving ships. Altogether, the NWS has about 5000 full-time employees working in meteorological and hydrological operations. In one year, approximately 3.5 million observations are taken and 2 million forecasts and warnings issued. Additionally, countless individual briefings and services are provided on a routine but unscheduled basis.

The NWS facilities which are of concern to the DWS and the information flow between them are conceptually illustrated in Figure 3-1. Individual facilities are discussed in more detail in Appendix B, but their operations are also briefly described here.

The NWS presently receives data from an extensive network of observing facilities throughout the United States and in other parts of the world. While the vast majority of the domestic facilities are operated and maintained by the NWS, there are some which are operated by other government agencies, commercial organizations, and private individuals. In all cases, however, the data must meet certain NWS standards before it can be introduced into any of the national meteorological data communications systems.

Collection and distribution of the observational data are accomplished primarily via low-speed local, regional, and national teletypewriter circuits which deliver the information to a variety of user groups within the meteorological community. Most of the acquired data ultimately arrives at the National Meteorological Center (NMC) in Suitland, Maryland, where it is correlated, analyzed, and scientifically processed into a variety of products (analyses, prognoses, etc.), most of which are in graphic, i. e., map, form. Domestic distribution of the NMC graphic products is accomplished via

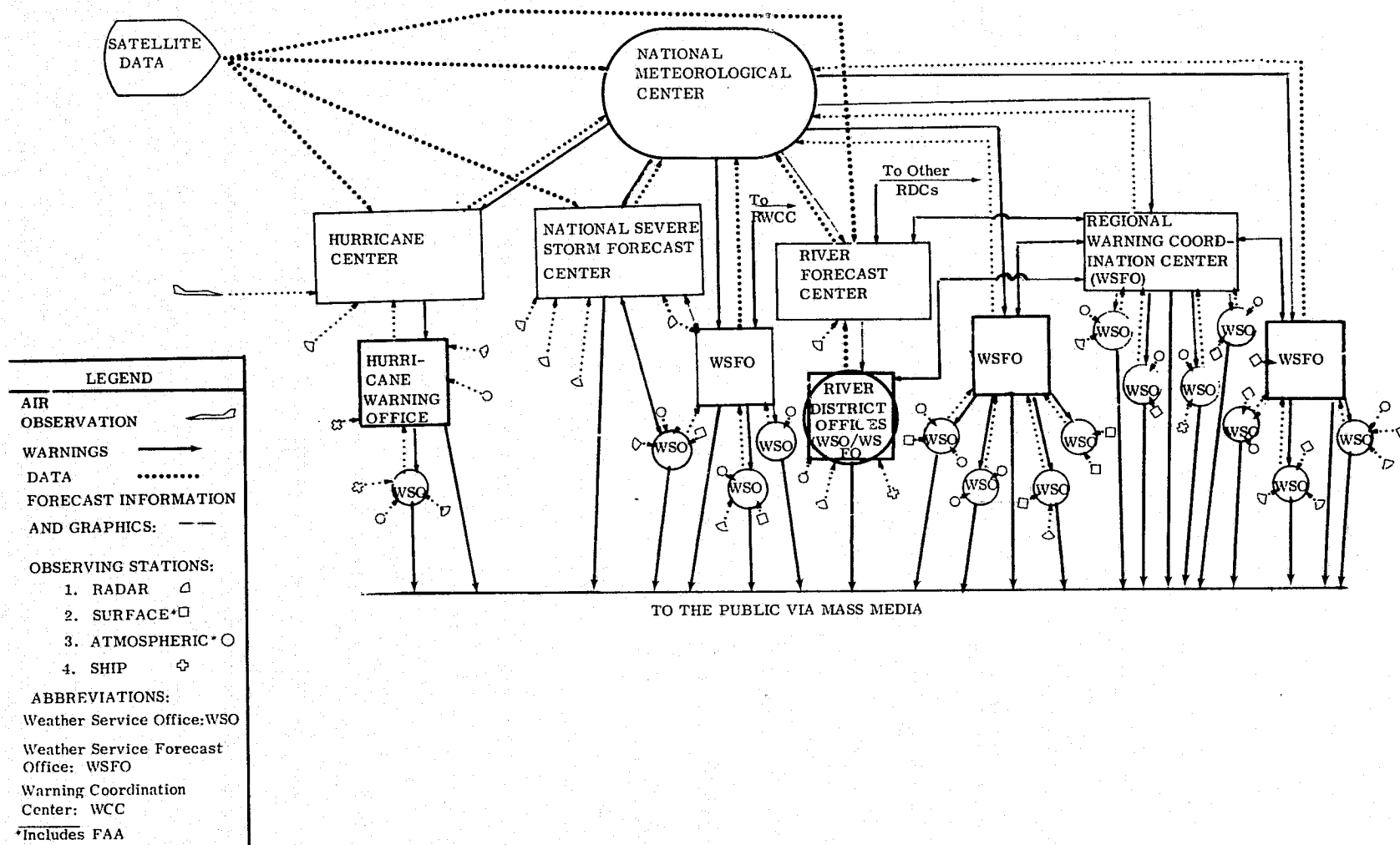


Figure 3-1. Representative Traffic Flow

several facsimile circuits, each of which provides national distribution of certain pre-defined classes of products. In addition to the NWS field facilities, facsimile circuit "drops" are available to virtually any organization or individual within the United States who is willing to buy or lease a facsimile recorder and pay the cost of the "drop."

3.2.1.1 Weather Service Forecast Offices (WSFOs)

The existing NWS field structure consists of almost 50 WSFOs, each of which is responsible for the generation and issuance of forecasts and warnings and other relevant products within a specified geographic area. Although there are some exceptions, forecast area boundaries generally coincide with state boundaries. Four WSFOs act as Regional Warning Coordination Centers (RWCCs) for larger regions. The RWCCs monitor and coordinate warnings of all hazardous weather and issue warning bulletins for severe winter storms. Data available within the WSFOs consist, as a minimum, of all local and regional teletypewriter circuit data, a limited amount of national teletypewriter circuit data, and a selection of NMC graphics. The average WSFO receives about 200 NMC-generated graphic products per day which are stored in hard copy form (paper). In addition to teletypewriter and NMC facsimile circuit data, all WSFOs have voice communications with both NWS and non-NWS area observers and may have a collocated NWS data acquisition function, i.e., surface, radar, upper air, or any combination. Some WSFOs also have a Weather Bureau Radar Remote (WBRR) receiver which provides a near real-time facsimile image of the video data from a remotely located NWS radar.

3.2.1.2 Weather Service Offices (WSOs)

Below the WSFOs in the NWS field structure are approximately 200 WSOs which receive local and regional teletypewriter data and, in most cases, a limited number of NMC-generated facsimile charts. Although the basic forecast responsibilities of the WSOs are limited, they are responsible for preparation of local warnings and refinement and/or revision of the WSFO products to render them more meaningful to the local populace. Like the WSFOs, the WSOs disseminate forecasts, warnings, etc., but their service areas are much smaller. Some WSOs have WBRR receivers and virtually all have a data acquisition responsibility.

3.2.1.3 Weather Service Meteorological Observatories (WSMOs)

The lowest level NWS field station is the WSMO which normally has data acquisition responsibilities only. WSMOs have a single teletypewriter "drop" for entering their data into the system, and have no forecast or warning responsibilities.

3.2.1.4 River Forecast Centers (RFCs)

At essentially the same level as the WSFOs in the field structure are the 12 RFCs. The RFCs collect and process hydrological and meteorological data and prepare river

forecasts and warnings for primary points along river systems. Like the WSFOs, the RFCs receive area and regional teletypewriter data and selected NMC graphics. Weather radar data are used extensively at RFCs along with data acquired from high density rain gauge fields, snow depth measuring devices, etc., which are established and operated primarily for hydrologic applications. RFCs and WSFOs are normally collocated where operational requirements permit.

3.2.1.5 River District Offices (RDOs)

Below the RFCs in the NWS field hydrologic services structure are about 80 RDOs which relate to the RFCs in much the same way as the WSOs relate to the WSFOs. The RDOs are collocated either with WSFOs or WSOs. RDOs collect data and forward it to the area RFC, receive RFC products (forecasts, warnings, alerts, etc.), tailor them for local application, and disseminate them within their assigned service area.

3.2.1.6 Other National Centers

The only remaining major facilities to be covered in the NWS field operations structure are the National Hurricane Center (NHC) collocated with the WSFO in Miami, Florida, and the National Severe Storms Forecast Center (NSSFC) in Kansas City, Missouri. These two national centers function much like WSFOs except their areas of responsibility are defined in terms of meteorological phenomena rather than geography. The NHC is responsible for all technical matters pertaining to Atlantic hurricane predictions and warnings, while the NSSFC has nationwide responsibility for preparation and issuance of local severe storm (including tornado) forecasts. Both the NHC and the NSSFC have on-site data processing capability and both have access to all local, regional, and national teletypewriter and graphic data. The NHC also collects data directly from the Caribbean and South Atlantic areas.

The Cooperative Hurricane Reporting Network (CHURN), consisting of about 100 stations along the Gulf of Mexico and Atlantic coasts, provides surface weather observations upon request by the NWS. These observations supplement the regular observations in times of threatening weather; i.e., hurricanes, tropical storms, and other storms along the coast. One-third of the CHURN stations are Coast Guard stations.

Hurricane forecasts and warnings in the Eastern Pacific (east of 140 degrees west longitude and from the Equator to 50 degrees north) are the responsibility of the Eastern Pacific Hurricane Center, collocated with the San Francisco WSFO. The Central Pacific Hurricane Center in Honolulu, Hawaii is responsible for the tropical cyclone forecast and warning program in the Central Pacific (from 140 degrees west to the 180th meridian and from the equator to 50 degrees north latitude).

Aerial reconnaissance of hurricanes is performed by the military services coordinating with the various NWS hurricane centers.

Several generalizations concerning traffic flow which are useful for analyses are:

- Data is usually collected by lower echelon facilities (WSOs) and transmitted upwards.
- NMC prepares nationwide forecasts and graphics material which is transmitted to lower echelon facilities (first, the WSFOs) for preparation of area forecasts. Forecasts (and warnings) are then relayed to WSOs.
- Warnings may be disseminated to the public via mass media from several echelons; however, the responsibility for dissemination of warnings rests principally with the WSO.
- There is a great deal of collocation of facilities (e.g., the RDOs can be either WSOs or WSFOs.)

These generalizations are particularly useful when one considers the implementation of planned systems such as the Automation of Field Operations and Services (AFOS) which is described in Appendix C. The projected impact of AFOS on the traffic flow is described briefly in the following paragraphs.

3.2.2 Future

Planning the DWS necessitates certain assumptions about the form of the future NWS. The most important aspect of the future configuration of the NWS involves the implementation of AFOS. The simplest and most likely assumption concerning the implementation and operation of AFOS is that it will evolve as currently planned. The following discussion of the DWS is based on this assumption.

The synoptic data which is transmitted to the NMC by WSFOs will be carried by the National Digital Circuit (NDC), a closed loop configuration connecting the WSFOs, the National Centers, and the RFCs. The NDC will replace the FAA Service A and C circuits which presently perform this function; however, the FAA will still transmit airport observations on their own circuits. NDC will replace Services A and C only as far as the NWS is concerned. Pictorial data and other graphics will still be carried by the facsimile circuits such as FOFAX due to the constraints on quantity and rate of data to be transmitted on the NDC. Data transmitted to the WSFOs from the WSOs will also be via automated links implemented as spurs from the NDC. There also will be some automation of the delivery of data to WSOs from observing stations; in fact, this process has already begun.

Interactions between the (future) NWS and DWS are illustrated in Figure 3-2. The DWS functions may include:

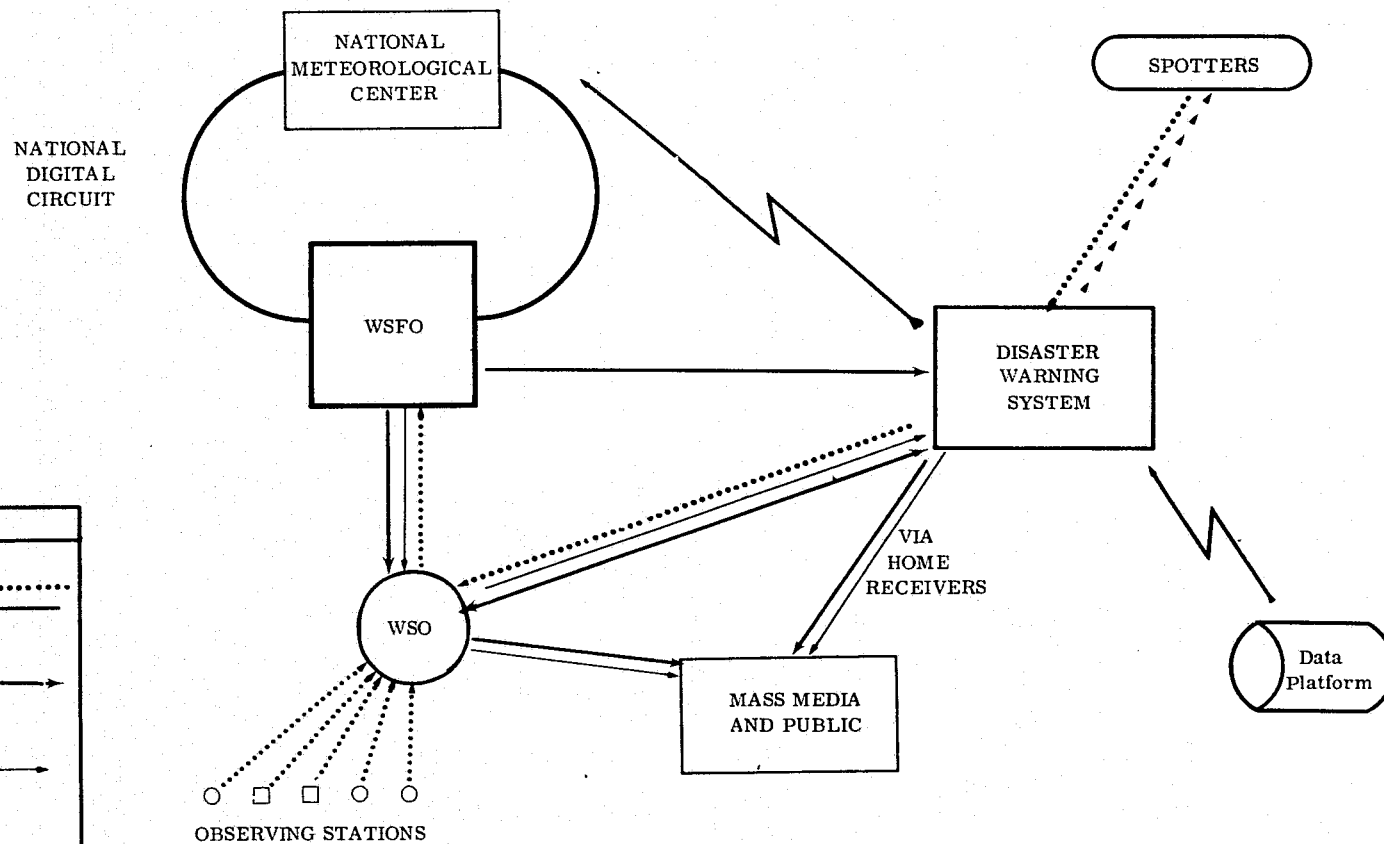


Figure 3-2. Implementation of DWS with AFOS

- Delivery of warnings to public
- Spotter alerting and reporting
- Data collection
- Coordination among NWS facilities
- Broadcast of routine weather information

The principal function envisioned for the DWS is the delivery of urgent data (that which does not have time to traverse the NDC) such as observations concerning flash floods and tornadoes, and the alerting and warning of the public through individual home receivers. Secondary DWS functions may include relaying data from remote platforms and continuous broadcasting of routine weather forecasts to be received by the home receiver. The urgent data that DWS may carry includes observations from spotter networks previously alerted (either through DWS or by other means). This data is relayed to the relevant WSO which accesses the DWS to broadcast a warning, if necessary. The WSFOs and RFCs would also have the ability to access the DWS to issue warnings as well as the WSOs, RDOs, and the NSSFC.

It is worth noting that the DWS also provides the capability for the WSFO to alert the WSO regarding the existence of hazardous weather. This capability may seldom be needed but situations may arise in which it would be useful.

3.3 PLANNED WARNING SYSTEMS

3.3.1 NOAA VHF-FM Broadcasts

There are presently 65 VHF broadcasting facilities located near large urban and coastal areas. Approximately 40 percent of the population is within the nominal coverage area of 65 kilometer radius from these transmitters. Each of these transmitters, operating at either 162.40 or 162.55 MHz, is controlled by a local NWS Office (typically a WSFO or WSO) which supplies a local forecast. This forecast is continuously sent 24 hours a day with the taped messages being repeated every 4 to 6 minutes. The forecasts are updated as required, typically every 2 to 3 hours.

This system also has the capability to demute specially designed receivers by sending the proper tone, thus providing a positive alert of hazardous conditions. This alerting function is being used primarily to alert schools, hospitals, and other places of assembly, public utility units, emergency forces, and news media. General public use of this alerting function is expected as receivers containing this capability become more readily available.

This system is presently being expanded and approximately 175 transmitters are planned by 1978. Approximately 300 transmitters will be required to provide coverage to 90 percent of the population.

3.3.2 Decision Information Distribution System

The Decision Information Distribution System (DIDS) is being developed by the Defense Civil Preparedness Agency (DCPA) to provide a capability for simultaneous nationwide issuance of attack warnings. Since this is an attack warning system, reliability and survivability (particularly against an EMP threat) are emphasized rather than factors such as broadcast area selectivity and high data rates. The system concept is to utilize a small number of low frequency broadcasting terminals providing nationwide coverage and a 24-hour a day capability to demute receivers and deliver warning by voice, teletypewriter, and remote siren control. The primary users will probably be located at national, state, and local emergency operating centers, Federal and State agencies, national and local warning points, State adjutant and military headquarters locations, and broadcast radio and television stations. Additionally, inexpensive DIDS receivers are expected to be available for purchase by the general public.

The presently planned DIDS will consist of three National Warning Centers (NWCs) connected via leased wire services to two high power (200 kW), low frequency (61.15 kHz) control transmitters. A distribution system consisting of ten medium power (50 kW) low frequency transmitters (each at a unique frequency ranging from 160 to 190 kHz) will provide coverage to 99 percent for siren control and 96 percent for voice messages of the Continental United States (CONUS) population. Geographic selectivity can be achieved by utilizing the available code in the demuting signal.

Under the Disaster Relief Act of 1970, the use of the DCPA warning system is authorized to provide warnings of natural disasters. Under this authorization, a configuration by which the NWS could access the DIDS has been formulated. This concept has a control point (under NWS operation) at the WSFO closest to each of ten DIDS distribution transmitters. The other NWS warning facilities (247 facilities consisting of most of the remaining WSFOs and WSOs) have access to the DIDS through these control points. The number of accesses into each control point varies from 10 to 35. Whenever a NWS facility initiates a warning message, a header record, in addition to the warning message, is sent to the appropriate control point. The header will contain an originator ID code, destination address code, priority code, and a code to specify whether the warning message is voice or teletype. Upon receipt of the message at the control point, the header code will be authenticated, formatted for transmission on DIDS, and either sent to the DIDS transmitter via a dedicated leased line or taped for transmission at a later time if a queue exists.

3.4 GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SATELLITE

The collection of meteorological data from a large number of remote (unmanned) ground platforms is one of the functional requirements for the DWS. This data collection function is soon to be performed by the Geostationary Operational Environmental Satellite (GOES), scheduled to be launched in the last half of calendar year 1974. The basic purpose (in terms of impact upon satellite design) of GOES is to provide earth imaging, both visual and infrared, from synchronous altitude. Since a large number (perhaps up to tens of thousands) of data collection platforms (DCPs) will be implemented for use with GOES, any new satellite data collection capability would most likely have to be compatible with the DCPs to be deployed.

The DCPs' communication characteristics are given in Table 3-1. To meet the interrogation signal requirements, a satellite EIRP of 16 dBW is required with an additional 6 dB for DCPs with low elevation angles. A satellite G/T of -21.5 dB/°K is required to satisfy the data uplink requirements. The satellite multiple access is accomplished by a combination of time and frequency multiple access.

DCPs are assigned frequency channels and time slots (either in response to interrogation or self-timing). The satellite must have a receiver bandwidth of 300 kHz to accommodate the 150 channels indicated in Table 3-1. These channels are used domestically; there are 33 additional 3 kHz bandwidth channels for international use which utilize the frequencies from 402.0 to 402.1 MHz. In the GOES the UHF signals are cross-strapped to an S-Band transponder for the link to the control station located at Wallops Station, Virginia. The link to a control station is not constrained by the GOES configuration; however, use should be made of the baseband equipment and control techniques that have been developed for GOES.

3.5 SUMMARY

The conceptual traffic flow of the future (~1985) NWS is illustrated in Figure 3-3. The three major types of traffic are: data collection, forecast materials, and forecasts and warnings. Meteorological data flows from the lower echelons up to the NMC, forecast material originates at the NMC and flows to the lower echelons, and the forecasts and warnings originate at the middle and lower echelons and are passed to the general public.

The primary communication configuration consists of a full access network together with the lower echelon facilities connected to nodes of the larger network. The full access network (AFOS), illustrated as circles connected in a loop in Figure 3-3, connects all the WSFOs, RFCs, and National Centers and all traffic is accessible to all facilities. In Figure 3-3, two loops are illustrated; however, in the actual implementation, one network will carry all the illustrated traffic.

Table 3-1. Data Collection Platform Communication Characteristics

Characteristics	Interrogation Signal from Satellite	DCP Signal to Satellite (Interrogated DCPs only)	DCP Signal to Satellite (Self-Timed DCPs only)
Frequency (MHz)	468.825	401.850 to 402	401.700 to 401.850
Number of Channels	1	100	50
Channel Spacings (kHz)	N/A	1.5	3.0
Modulation	$\pm 70^{\circ}$ PSK, Manchester Coded	$\pm 70^{\circ}$ PSK, Manchester Coded	$\pm 70^{\circ}$ PSK, Manchester Coded
Baud Rate	100	100	100
Message Duration (seconds)	0.5	60	60
Error Rate	10^{-6}	10^{-6}	10^{-6}
Emergency Requirements	Time Slots Reserved for Priority Interrupt	Frequency Channels Reserved to respond to emergency commands and data that exceeds preset threshold	Frequency Channels Reserved to respond to data that exceeds preset threshold

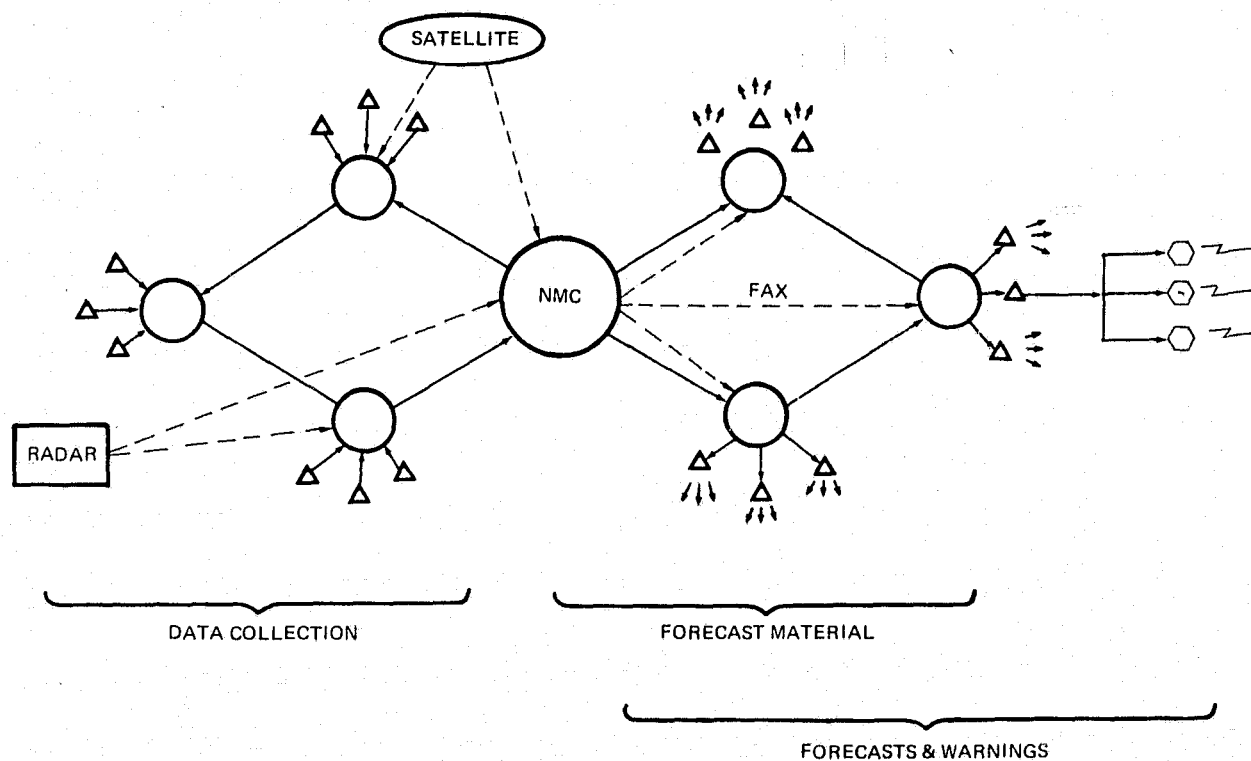


Figure 3-3. Conceptual Traffic Flow of Future NWS

The lower echelon and facilities (e.g., WSOs), illustrated as triangles in Figure 3-3, are connected to their parent facility. Data generally flows from these facilities and some of this data is then entered into the complete access network. Some of the forecast material is passed down to the lower echelons along with the localized forecasts. One of the basic functions of the lower echelon facilities is to provide forecasts and warnings to the general public. This information is passed to the public via the mass media using facilities such as the NOAA Weather Wire Service (NWWS) and a DWS directly to home receivers. This dissemination is illustrated by the hexagons in Figure 3-3.

Generalizations can be made concerning the traffic in the full access network; but not for the networks connecting the lower echelons to their parent facilities. Each facility must be treated individually since they are tailored to the particular locale. Furthermore, all traffic within a particular spur network is not necessarily received by all nodes of that network. For example, data may be preprocessed or only used locally to adopt and refine forecasts received from the parent facility.

Some auxiliary traffic is also illustrated in Figure 3-3. Satellites will be used to obtain meteorological data such as earth and cloud coverage images and data from remote platforms. This data will go directly to the NMC; however, some of the data may also be received directly from the satellite at some special facilities. The high resolution imagery will be sent over facsimile networks via the Satellite Field Services Station to the WSFOs, RFCs, and the National Centers. Also, the RAWARC network will continue to provide radar data to selected facilities.

Table 3-2 summarizes the estimated traffic loading of the future NWS illustrated in Figure 3-3. Other than the warning and satellite imagery traffic, the estimates are from the AFOS requirements. No estimates were made of the (nonwarning) traffic to and from the lower echelons since each facility must be considered individually. The amount of traffic is most likely bounded by the values presented for AFOS and the average is probably approximately 1/50 of those values.

The estimated satellite imagery traffic is based upon 19 sectors of either visual or IR images plus four sectors of IR images being transmitted every 30 minutes. The images are transmitted using analog signals and requires approximately 20 minutes to transmit a single image over C5 conditioned land lines.

The estimated warning traffic is based upon the results of Section 4. Each warning message was estimated to be 1 minute long sent at a rate of 150 words per minute. The effects of this traffic load upon a DWS is discussed in detail in Section 4 and will not be repeated here.

Table 3-2. NWS Traffic Loading

	Messages/Day	Data/Day
Data Collection		
Surface	15,912	795,600 Characters
Synoptic & Radar	2,424	244,400 Characters
Forecasts		
FT-1, FT-2	2,268	203,840 Characters
Winds Aloft	582	146,000 Characters
State, Zone & Local	2,800	1,167,500 Characters
Special	990	832,000 Characters
Forecast Material		
Graphics	225	3,870,000 Bits
Satellite Imagery	1,104	368 Hrs. on C5 line
Warnings**		
HW	82	12,300 words
RW	101	15,150 words
TSSW	214	32,100 words
WSW	212	31,800 words
SCW	291	43,650 words
OW	185	27,750 words
<p>* Estimated from available data.</p> <p>** Worst case month</p>		

SECTION 4 - WARNING TRAFFIC PROJECTIONS AND QUEUEING

4.1 INTRODUCTION

One of the most critical system requirements is to have sufficient capacity to ensure that warning messages are received with minimum delay. To ascertain required system capacity, it is necessary to estimate the warning traffic loading and traffic statistics for the DWS operational period (1985), and to develop a model for handling and issuing warnings. Based upon the data provided by NOAA, traffic estimates are presented in Paragraph 4.2. These were used in a queueing model to estimate time delay (see Paragraph 4.3) incurred as a function of the number of channels in the system. Additional data analysis and a refined queueing model are being pursued by NASA Lewis Research Center, some of which is described in the Executive Summary, Volume I, of this report.

4.2 WARNING TRAFFIC PROJECTIONS

At the present time, it is difficult to determine accurately an upper bound for the disaster warning traffic for 1985. Perhaps the best method of estimating 1985 traffic is to monitor the warning traffic issued by a number of warning offices (WFSO or WSO) situated in disaster prone regions having a large number of manned and automated reporting stations. The monitoring operation would yield the average as well as the busy time (peak) traffic per unit time per unit station. Knowing the number of offices issuing warnings, and accounting for future NOAA plans for monitoring, analyzing, and reporting disasters, this data could be then used to directly estimate an upper bound for the disaster warning traffic. The advantage of such a method is that it takes into account real-world factors as much as possible. However, this type of data is not presently available and may not be for some time.

Future plans for improving the monitoring and reporting of disasters are described in References 2 and 4. However, it is doubtful whether this information alone can be used with confidence to estimate future warning traffic since the relation between quantity and/or quality of monitoring and reporting stations and number of warning messages is not known. Therefore, in view of the limitations, 1985 disaster warning traffic was estimated by extrapolation using available warning message data for the years 1966 to 1973. The method of estimating the warning traffic is described in the following paragraphs.

Two types of warning data were analyzed: weather warning and river warning. Weather warning data were provided for 87 months from January 1966 to March 1973. River warning (RW) data were provided for 74 months from January 1967 to February 1973. The weather warning data included: tornadoes and severe storm warnings (TSSW), hurricane warnings (HW), small craft and gales warnings (SCW), winter storm warnings (WSW), and other warnings (OW). Forecasts for inland lakes,

although included in the data, were not considered as warnings and therefore were not included in the estimate.

A linear regression analysis was performed on the aggregate and each category of the weather warning data (excluding hurricane warnings) and the river warning data to determine trends and seasonal variations. Hurricane warning traffic was estimated using the same procedure described in Reference 5. The upper 95-percent prediction interval (see Reference 6) was used as a conservative upper bound for traffic estimations for the aggregate weather and river warnings as well as each category of weather warning data. The correlation coefficients of the regressions were also calculated to obtain quantitative information about the linear growth with time of warning traffic. Appendix D contains a description of the formulations used in estimating the natural disaster warning traffic and the detailed results of the estimates.

To illustrate the estimation technique, the results for the tornado and severe storm warning traffic are shown in Figure 4-1. As can be seen, as time increases so does the estimation uncertainty and the corresponding margin to maintain the 95-percent bound. A comparison of the aggregate weather warning traffic estimates with those of its different categories (results contained in Appendix D) illustrates that the whole is not equal to the sum of its parts. The rates of increased warnings varied considerably for the different categories, but this information is somewhat masked when the categories are treated collectively. Consequently, the traffic projections must be done individually for each category and then added for the total weather warnings.

Seasonal variations for river and each category of weather warning were estimated on a monthly basis. The results were applied to 1985 traffic and are shown in Table 4-1. The peak 1985 monthly traffic load occurs in December as a result of seasonal contributions from WSW and SCW. The lowest traffic load occurs in August. Figure 4-2 provides a comparison of monthly warning traffic between the 1985 estimate (95 percent bound) and average traffic based upon the warning data. Due to the large monthly variances, the system capacity was based upon the highest monthly value (December).

4.3 QUEUEING RESULTS

The queueing model used was for Poisson arrival and exponential service distributions. Both a first-come-first-service (nonpriority) and nonpreemption priority service were considered. The detailed formulations and results of the queueing analysis are contained in Appendix E.

In addition to the number of channels, the two parameters in the queueing model are the mean arrival rate and the mean service rate, both expressed in messages per minute. The worst case traffic loading (December) of 21,405 messages per month is used to obtain a mean arrival rate of 0.4955 message per minute. A nominal mean

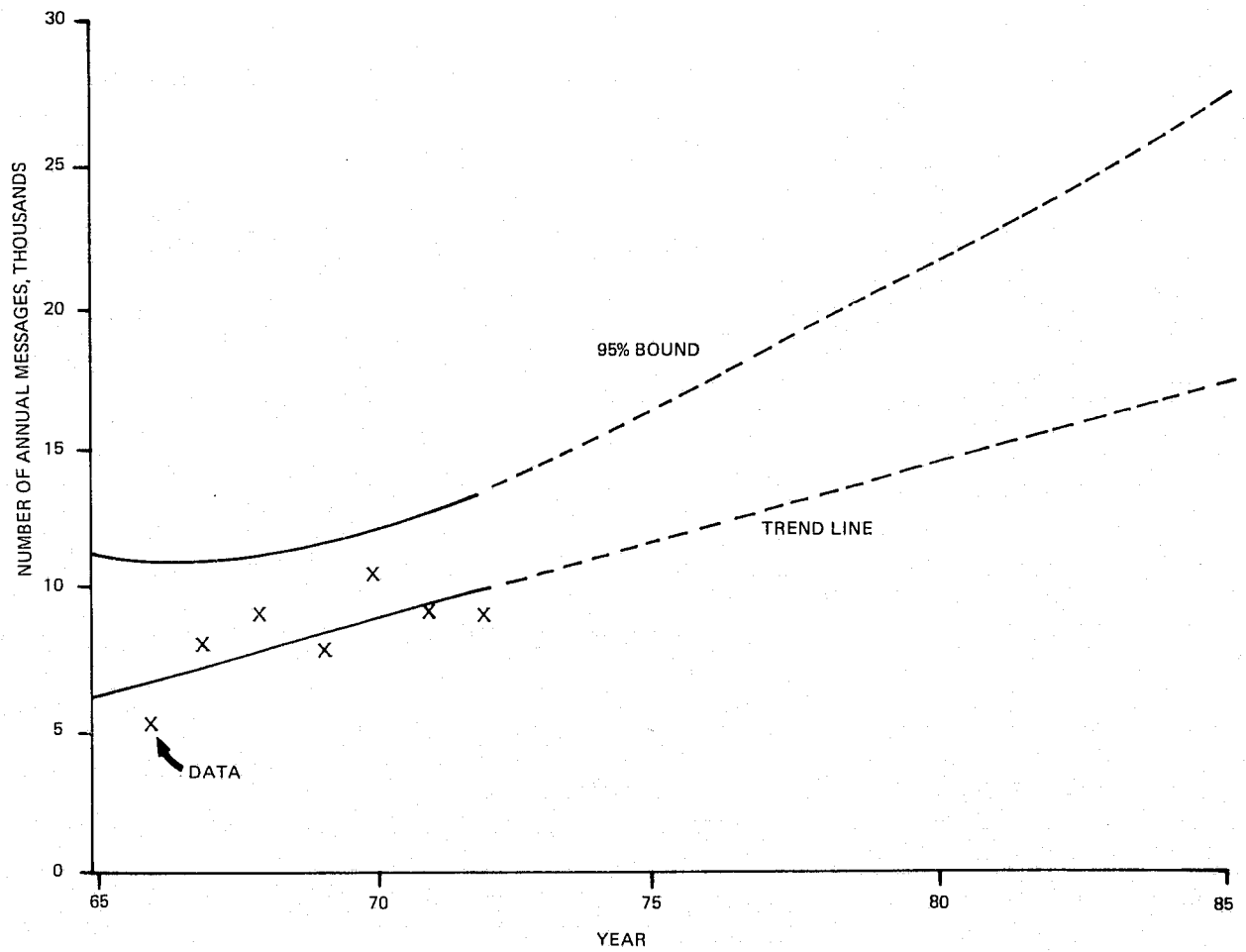
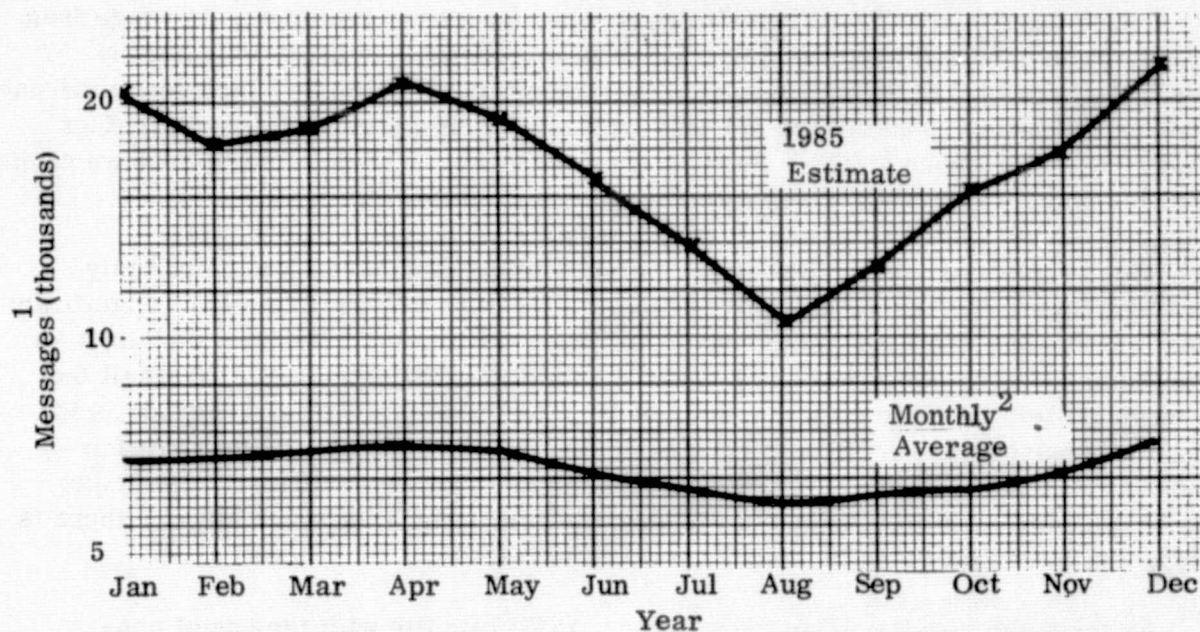


Figure 4-1. Tornado and Severe Storm Warning Traffic

Table 4-1. Estimated Monthly Load of Disaster Warnings for 1985 (95% Bound)

<u>MONTH</u>	<u>RW</u>	<u>TSSW</u>	<u>WSW</u>	<u>SCW</u>	<u>OW</u>	<u>TOTAL</u>
Jan	1535	308	6376	6220	5544	19983
Feb	1535	662	4286	6809	4243	17535
Mar	1535	1443	3508	7503	4412	18401
Apr	2139	4543	1977	7451	4241	20351
May	3018	5948	345	5365	4195	18871
Jun	2371	6420	36	4378	3563	16768
Jul	1795	3527	4	4409	3748	13483
Aug	1339	1940	45	3881	3979	11184
Sep	1250	1028	262	6069	4206	12815
Oct	1502	811	1391	7949	4398	16051
Nov	1480	363	2365	8434	4619	17261
Dec	1607	583	5521	8726	4968	21405
Total Year	21,106	27,576	26,116	77,194	52,116	204,108



- 1 - Warning messages include RW, TSSW, WSW, SCW and OW.
2 - Based upon weather and river warning data.

Figure 4-2. Comparison of Monthly Traffic From Data And 1985 Estimates

service rate of 1.008 messages per minute is used based upon the average length of 21 types of weather service warnings and assuming a speaking rate of 137 words per minute (Reference 5). The queueing results without priority are shown in Figure 4-3 in terms of the probability of waiting more than one minute in the queue. Queue waiting time corresponds to the time from the moment one attempts to send a message to the time the transmission actually begins. The probability of waiting more than one minute is 6×10^{-5} for four channels. To illustrate the sensitivity to service time, the results for a mean rate of 0.625 message per minute is also shown.

These results are for all types of warnings whose time requirements range from a minute to an hour. A nonpreemptive priority service was investigated whereby priority 1 warnings are given preference over priority 2. Priority 1 includes hurricane warnings, tornadoes, and severe storm warnings, and 10 percent of other warnings including disasters such as flash floods and earthquakes. The detailed breakdown of the priorities and the monthly arrival rates is given in Appendix E.

The detailed results and the variations that were considered for the priority queueing are in Appendix E, and only the general results will be discussed. Significant reductions in expected time in the queue were achieved for the priority 1 warnings for low numbers of channels. At higher channel numbers, time in queue is so small that use of priorities has little effect on the results. Another factor of significance is the ratio of the number of warnings in each of the priorities. Whenever there are few messages in priority 1, the improvement of priority over the nonpriority service is significant. However, as the number of priority 1 messages becomes larger, there is little improvement of priority over nonpriority service.

Although the results do not show large overall benefits with the use of non-preemptive priority service, the use of this type of service is recommended. There is an advantage of getting critical warnings out, particularly during peak loading. The results in Appendix E are only the expected values (no applicable models were readily available that would provide additional statistics for the nonpreemptive priority service); thus, performance during peak loads is not shown. Furthermore, a more restrictive selection of priority 1 disasters would improve the performance of the priority service.

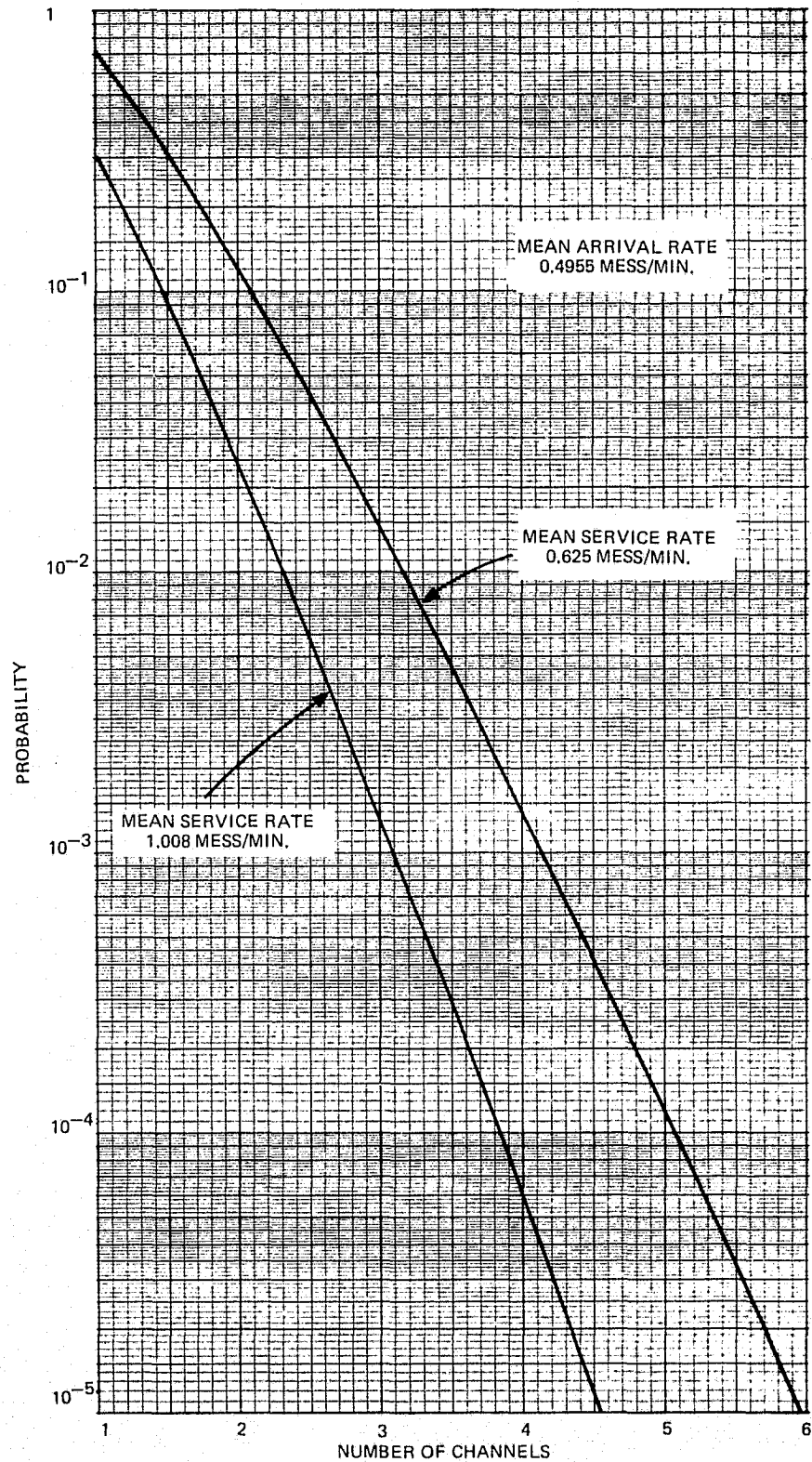


Figure 4-3. Probability of Waiting in Queue
More Than One Minute

SECTION 5 - NOAA DWS REQUIREMENTS

5.1 INTRODUCTION

This section summarizes the NOAA requirements for DWS which were originally transmitted to NASA on June 27, 1972 in a letter from the Associate Administrator of NOAA. During the course of the study these requirements were clarified or modified where necessary in discussions with representatives of the NASA/NOAA DWS Working Group. All details of the resultant requirements are not presented in this section, only those with a primary influence on the resulting conceptual designs. The requirements specified by NOAA generally do not quantitatively specify communication performance such as required signal-to-noise ratios, data error rates, or data rates. Engineering judgements were used to quantify specific requirements and are contained in the detailed discussions in Sections 6 and 7. The requirements presented here are categorized into functional requirements, required response to disaster types, operational requirements, geographical coverage, and capacity requirements.

5.2 FUNCTIONAL REQUIREMENTS

NOAA specified some 15 different requirements for information to be transmitted (Table 5-1). These requirements result in basically four distinct communication services or functional requirements to be provided by DWS. The four functional requirements and the corresponding requirements from Table 5-1 are:

- Disaster warning (A.2.a, A.2.c, A.3, A.5, B.1)
- Spotter reporting (A.1.a, A.2.b, A.7)
- Data collection (A.1.b, A.1.c, B.3)
- Coordination (A.4, A.6, B.2)

Note that all communications requiring a voice format and reaching the general public are grouped under "disaster warning." All communications to or from spotters are grouped under "spotter reporting" and also require a voice format. All communications of digital data are grouped under "data collection." Finally, those communications involving primarily weather service facilities are grouped under "coordination" and require a voice format. Subsequent descriptions of the DWS concepts are given in terms of these four functional requirements. The major impacts on the DWS are caused by the "disaster warning" and "spotter reporting" functions.

Table 5-1. Information Required to be Transmitted

CATEGORY	ORIGIN	DESTINATION	FORMAT*	DUTY CYCLE	AREA OF COVERAGE
I. MANDATORY REQUIREMENTS					
A. INFORMATION TRANSMITTED DURING DISASTERS.					
1. Disaster Data Collection:					
a. Information from Spotter Networks	Any one of 100,000 police, fire, civil defense and local authorities	WSFO, WSO & NWC	Voice, half duplex	1 minute to continuous	Within geographic area of responsibility
b. Data from Hurricane Reconnaissance aircraft	Up to five aircraft simultaneously	Miami, NWC	Digital data	1 sample per 10 seconds for 5 hours at 7 bits per sample	Anywhere within 0° to 50°N. Latitude 35°W Longitude to 105°W. Longitude
c. Automatic Data Collection Platforms	Any one of 20,000 platforms	WSFO, WSO, RFC & NWC	Digital data	100 bits (average) for 1 to 30 seconds every 15 to 60 minutes	Within geographic area of responsibility
2. Disaster Information:					
a. Issue Watch Bulletins	WSFO & NWC	General Public Public Officials News Media WSO	Voice Voice, Hard Copy Voice, Graphics for TV Voice, Hard Copy	100 words to 300 words as required, update as required	Within geographic area of responsibility
b. Alerting Spotter Networks	WSFO, WSO, & NWC	Spotters	Voice	50 to 100 words as required	Within geographic area of responsibility
c. Preparedness Information and Safety Rules	WSFO, WSO, & NWC	General Public News Media	Voice Voice, Graphics for TV	300 to 500 words Repeat every 15 minutes for 3 hours	Within geographic area of responsibility
3. Disaster Warnings	WSFO, WSO, & NWC	General Public News Media	Voice Voice, plus Hard Copy Graphics for TV	Warnings: 100 to 150 words--repeat as frequently as necessary Statements: 50 to 100 words--repeat every 15 minutes; update each hour Cancellations: 50 wds.	Within geographic area of responsibility

Table 5-1. Information Required to be Transmitted (Cont'd.)

CATEGORY	ORIGIN	DESTINATION	FORMAT*	DUTY CYCLE	AREA OF COVERAGE
4. Radar Information	WSFO, WSO & WSMO	Public Officials News Media Spotters WSO	Voice Voice, Digital/Graphics Voice Voice, Digital/Graphics	Repeat every 5 minutes	Within 150 miles of primary radars
5. Evacuation Information	WSFO, WSO, & NWC	General Public	Voice, plus Hard Copy	As required	Within geographical area of responsibility
6. Coordination	WSFO, RFC, WSO, NWC & WSMO	WSFO, RFC, WSO, NWC & WSMO	Voice, Full Duplex	Continuous, as required	Within geographical area of responsibility
7. Communications for rescue and relief and damage assessment.	Any one of 100,000 police, fire, civil, defense, and local authorities	State Officials and National Organizations WSFO, WSO & NWC	Voice, Half Duplex	1 minute to continuous	Within geographical area of responsibility
I. INFORMATION TRANSMITTED DURING NORMAL TIMES					
1. Education for what to do when a disaster strikes	WSFO	General Public News Media	Voice Voice, Graphics for TV	Continuous, as required	Contiguous U.S., Alaska and Hawaii
2. Planning Information	WSFO & NWC	WSO	Voice, full duplex, plus Hard Copy	150 to 300 words once per six hours	Within geographic area of responsibility
3. Collection Platforms	Any one of 20,000 Data Collection Platforms	WSFO, WSO, RFC, & NWC	Digital Data	100 bits (average) for 1 to 30 seconds--data repeats 6 hours	Within geographic area of responsibility
II. NON-MANDATORY REQUIREMENTS					
B. INFORMATION TRANSMITTED DURING NORMAL TIMES					
1. Dissemination of Routine Forecasts and Information	50 locations distributed throughout contiguous U.S., Alaska and Hawaii	General Public in 50 locales	Voice Voice, Graphics for TV	Continuous--repeat every 6 minutes	Contiguous U.S., Alaska and Hawaii

*Voice transmitted at a rate of 150 words per minute
 Digital data transmitted at a rate of 100 bits per second
 Hard copy transmitted at a rate of 100 words per minute
 Radar data transmitted at a rate of 2400 bits per second

5.3 REQUIRED RESPONSE TO DISASTER TYPES

NOAA specified the maximum time for a warning message to get on-line to the general public and the smallest areas to be warned. These requirements are presented in Table 5-2. Actual warning traffic data supplied by the NWS for the study were broken down into a smaller number of major categories than in the table, so it was necessary to consolidate the requirements to reflect these categories. Discussions between NASA and NOAA determined that these requirements could be consolidated as follows:

Disaster Type	Smallest Area Warned	Message On-Line Upper-Bound
Tornado or Severe Storm	Part of county	1-5 minutes
Hurricane	Part of coast	1-15 minutes
River Flood	Part of state	15 minutes-1 hour
Small Craft Warning	Part of coast (lake)	15 minutes-1 hour
Winter Storm	Part of state	15 minutes-1 hour
Others	Part of county	1 minute-1 hour

The "Others" category includes flash floods, storm tides, unusual lake winds, live-stock advisories, frost, fog, radar summaries, special marine warnings and air pollution.

The on-line time requirement refers to the time from the moment one attempts to send a message to the time the transmission actually begins.

5.4 OPERATIONAL REQUIREMENTS

Some of the general system requirements are a continuous 24-hour operation and immunity to natural disasters; this implies an autonomous power source to avoid total dependence on commercially available power. Any of the NWS facilities within the DWS (down to the WSO and equivalent levels) has the authority to independently issue warnings and the DWS must be able to provide the capability for simultaneous warnings.

A key element in the DWS is the home receiver. In addition to low cost and ease of installation and operation, the receiver must be able to operate with an inside antenna and be activated (demuted) within 15 seconds after transmission begins. To avoid unnecessary warnings and to improve the warnings' effectiveness, the system must have the capability to selectively warn the general public. The DWS must

**Table 5-2. Disasters--Maximum Warning Time To Get Message
On-Line To General Public and Smallest Areas To Be Warned**

<u>Disasters</u>	<u>Time</u>	<u>Area*</u>
1. Severe Local Storms:		
a. Tornadoes	1 min	Part of County
b. Severe Thunderstorms	1-5 min	Part of County
2. Flash Flood	1 min	Part of County (Flood Plain)
3. Lake Seiche	1-5 min	Segment of Lake Coastline
4. Tsunami	1-5 min	Segment of Coastline
5. Earthquake	1-5 min	Part of County (Segment of State)
6. Volcanoes	1-5 min	Part of County
7. Landslides and Avalanches	1-5 min	Part of County
8. Oil Spills	1-5 min	Segment of Coastline
9. Accidents (e. g. , Chlorine Barge)	1-5 min	Part of County
10. Hurricane (Tropical Storms)	1-15 min	Segment of Coast line
11. Forest and Grass Fires	5-15 min	Part of County
12. Winter Storms (blizzard, heavy snow, ice storm, freeze or frost, cold-wave, high winds)	15 min - 1 hr	Portion of State
13. Storm Tides	15 min - 1 hr	Segment of Coastline
14. River Flooding	15 min - 1 hr	Part of State (Flood Plain)
15. Air Pollution	1 - 6 hrs	Metropolitan Area
16. Civil Disturbances Riots, Attack Warnings--Not an NOAA requirement		

*Coastal Area - 50 mi off coast--length variable

County = 20 x 20 mi (400 sq mi)-- average

Segment of Coastline = Up to 10 mi in-land, length is variable

be able to warn any one of 20,000 different areas (approximately subcounty size) and must be able to reach 99 percent of the population within any one of these areas during a disaster and 90 percent of the population during nondisaster periods. Since the 20,000 areas will be selected according to natural disaster potentials, the areas will tend to overlap in many cases (e.g., subcounty, county and portion of a state). Hence, each home receiver is specified to have at least three addresses.

5.5 GEOGRAPHICAL COVERAGE

The DWS geographical coverage requirement, illustrated in Figure 5-1, includes the area from the equator to 50 degrees North Latitude and from 35 degrees West Longitude to 180 degrees West Longitude plus Alaska. The number of simultaneous warnings may be anywhere within this broad area or concentrated within a small area such as a portion of a state.

5.6 CAPACITY REQUIREMENTS

The DWS capacity requirements are discussed in the context of the four functional requirements presented earlier. For disaster warning, NOAA specified that the system must be able to broadcast at least 10 simultaneous voice messages within a relatively large area such as a portion of a state or larger.* This requirement was further clarified for the coverage characteristics unique to satellite and terrestrial systems. A satellite system will tend to cover a large area with any single beam and in this case the requirement was modified to a requirement for 10 simultaneous transmissions within CONUS and four in areas outside CONUS. This requirement would also hold for low-frequency terrestrial broadcasting systems where coverage from a single transmitter can be quite large (multi-state). For line-of-sight terrestrial broadcasting (such as the NOAA VHF system which has a single transmitter coverage radius of about 65 kilometers) the requirement was modified to provide for two simultaneous channels within any one transmitter area.

For spotter reporting, there must be at least 50 half-duplex simultaneous voice channels between spotters in the field and the WSOs (nationwide). The number of simultaneous spotter reports into any particular WSO is limited to three. The requirement calls for 100,000 spotters nationally.

The data collection function requires 200 data channels during nondisaster periods and 200 channels during disaster periods. The estimated number of remote data collection devices is 20,000.

The coordination function was not specified and was assumed to require five full-duplex voice channels.

*This requirement was used for the baseline system. However, traffic and queueing analyses by both CSC and NASA Lewis Research Center have indicated that a lesser number of channels may suffice and this is addressed later in this report with alternative systems.

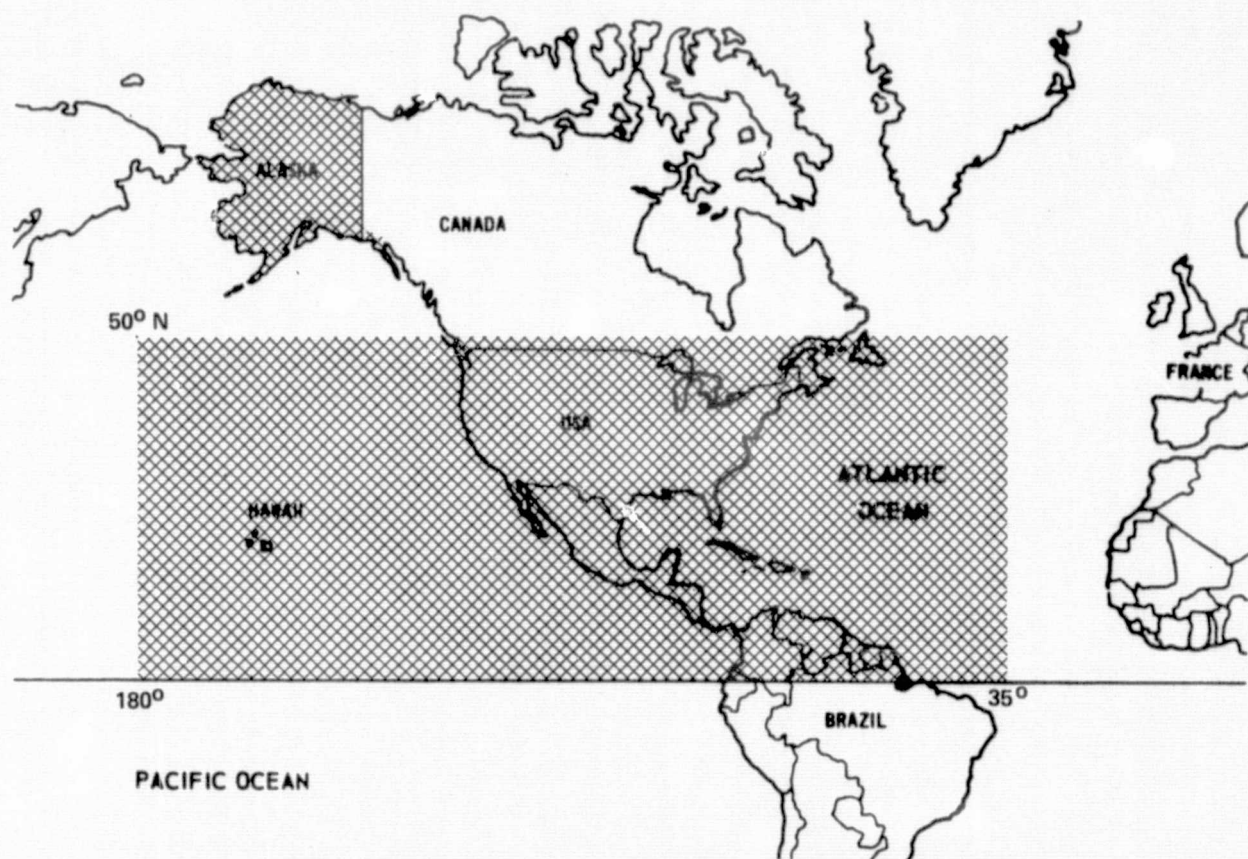


Figure 5-1. Geographical Coverage Requirement

SECTION 6 - TERRESTRIAL SYSTEM

6.1 INTRODUCTION

Of the four DWS functional requirements discussed in Section 6, disaster warning is implemented by terrestrial broadcasting, whereas the other three are implemented by terrestrial landlines. Much of the analysis of terrestrial broadcasting, presented in Paragraph 6.2, is concerned with the propagation properties required to determine appropriate broadcasting techniques. Implementation of the other three functional requirements is discussed in Paragraph 6.3. Finally, a base-line terrestrial system is presented in Paragraph 6.2.

6.2 DISASTER WARNING BROADCAST

A detailed propagation study was performed to determine the appropriate frequency band for broadcasting disaster warnings. The details of this analysis are contained in Appendix F, and are summarized herein. The frequency bands investigated ranged from low frequency (LF) through very high frequency (VHF). The UHF band, while not studied in detail, is similar to the VHF band and a number of characteristics can be inferred from the VHF results.

The cost of a terrestrial broadcast system depends to a large extent on how many stations are required. Since more transmitter power gives greater range, the tradeoff, in its simplest terms, is between individual transmitter cost and the number of transmitters required. For example, 10 transmitters may be required for an LF system to cover the 48 contiguous states, whereas up to 1000 VHF transmitters may be required for the same coverage. But each LF transmitter requires a tall tower, several acres of land, high power, elaborate electronics and cooling, and a separate enclosure, whereas the VHF transmitter requires modest power, and no major antenna construction or special housing. The LF transmitter would be considerably more expensive than the VHF transmitter in this case.

Because of the various advantages and disadvantages of radiowave propagation at any particular frequency, there is no clear-cut choice of frequency band for general terrestrial broadcast. Of course, for each alternative, the minimum signal-to-noise ratio for intelligible voice must be met or exceeded at each point in the area to be covered.

A hexagonal coverage pattern is assumed for each transmitter (Figure 6-1) with radius r and area $2.598 r^2$ to obtain the most efficient spacing of sites. This means that the closest distance between any two transmitters is nominally $1.732 r$ (siting of transmitters depends on topography conductivity, etc.). With the hexagonal pattern, only three different frequencies are required to avoid mutual interference as illustrated in Figure 6-1. Thus, the distance between any two transmitters having the same frequency would be $3 r$.

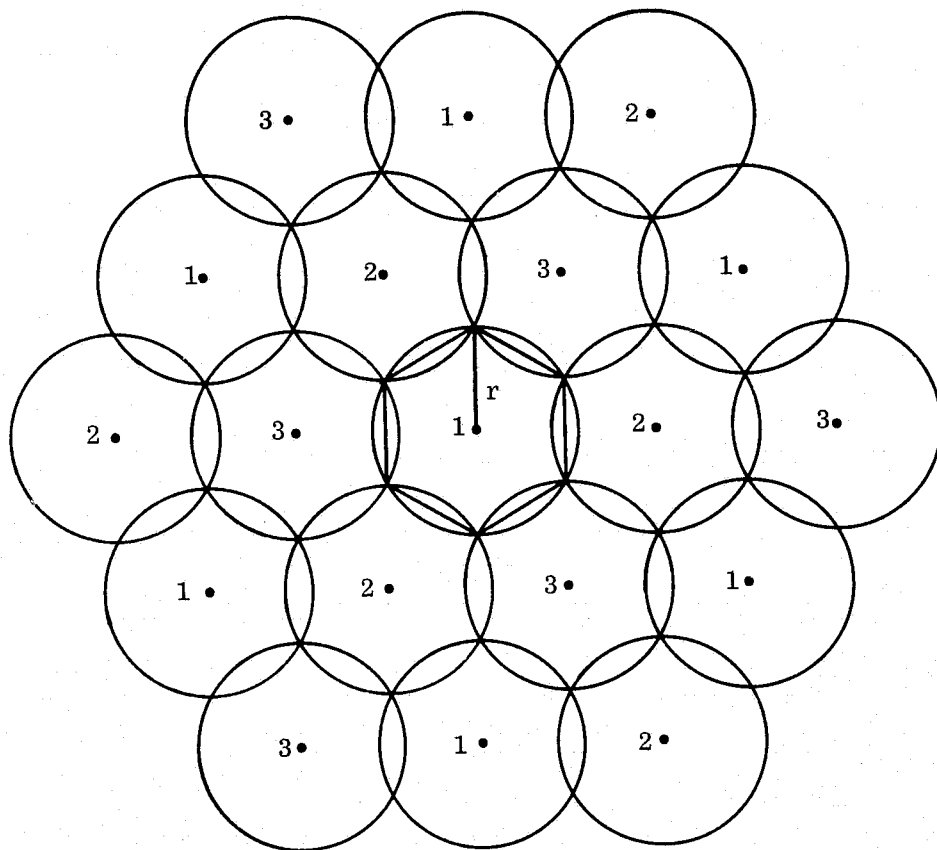


Figure 6-1. Hexagonal Coverage Pattern

To determine the number of transmitters required as a function of the transmitter power, some representative frequencies were chosen and investigated in detail (Appendix F). A summary of those results is presented here.

The LF band was characterized with frequencies of 150 and 300 kHz. In this band, atmospheric noise is strong, but noise suppression devices can be used to take advantage of the impulsive nature of the noise and improve the signal to noise ratio more than 20 dB. The skywave can be a problem at LF since it can be strong enough to interfere with the steady groundwave. Figure 6-2 shows the results of the coverage study at LF. At low transmitter power, the individual coverage radius is small. For such short distances, the attenuations at 150 and 300 kHz is the same. But the noise is greater at 150 kHz, so that more transmitters are required for a given power than at 300 kHz to obtain the same performance. The 150-kHz curve is steeper than the 300-kHz curve because the groundwave attenuation is less.

The HF band was characterized with frequencies of 3 and 30 MHz. This band has a high noise level from man-made sources but a low galactic noise contribution. The groundwave is more highly attenuated than at LF and, therefore, individual coverage areas will be significantly smaller for the same power level. During both day and night, the skywaves (single and multi-hop) are prominent; in fact, the HF skywave is an important mode of long-distance communication. The HF skywave is variable, therefore, not suitable for general broadcast usage on a single frequency. It does get strong enough to interfere with the relatively weaker groundwave at distant transmitters.

The VHF band was represented with 150 and 300 MHz frequencies. The noise in this band is a mixture of man-made and thermal, with the man-made noise losing strength at the higher portion of the band and on into the UHF band. No skywave is present, so interference will be from adjacent stations only. It is at these frequencies that attenuation by the building housing the receiver becomes significant, tending to increase with frequency. Unlike the LF band, at HF and beyond, antenna height becomes an important factor (Appendix F), producing a significant increase in the received signal strength as antenna height is increased. This is illustrated in Figure 6-3 for a fixed transmitter EIRP of 10 kW (additional data is presented in Appendix F).

Based upon propagation considerations, only the LF and VHF bands appear to be attractive for DWS terrestrial broadcasting. The HF skywave is unreliable and can cause unpredictable interference upon the reliable groundwaves.

The basic difference between the LF and VHF bands for broadcasting is that LF provides broad coverage using large antennas and high powered transmitters; whereas, VHF broadcasting is basically restricted to line-of-sight coverage resulting in relatively smaller antennas and lower transmitter powers. With the DWS requirement for at least 10 simultaneous voice broadcasts within a relatively small area (e.g., portion of a state), the broad LF coverage requires 10 voice channels from

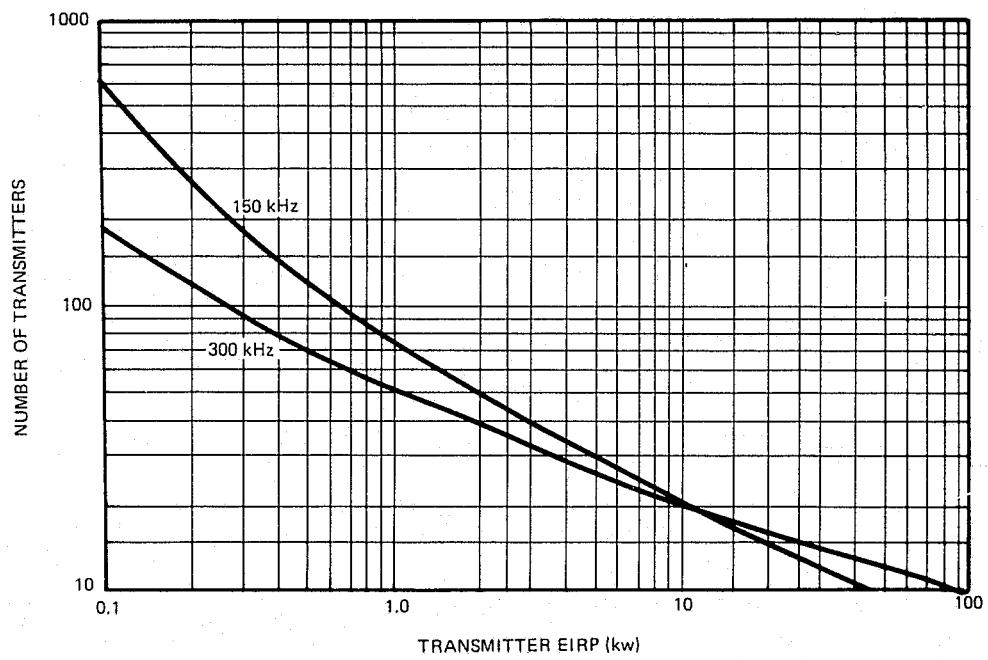


Figure 6-2. Coverage at LF

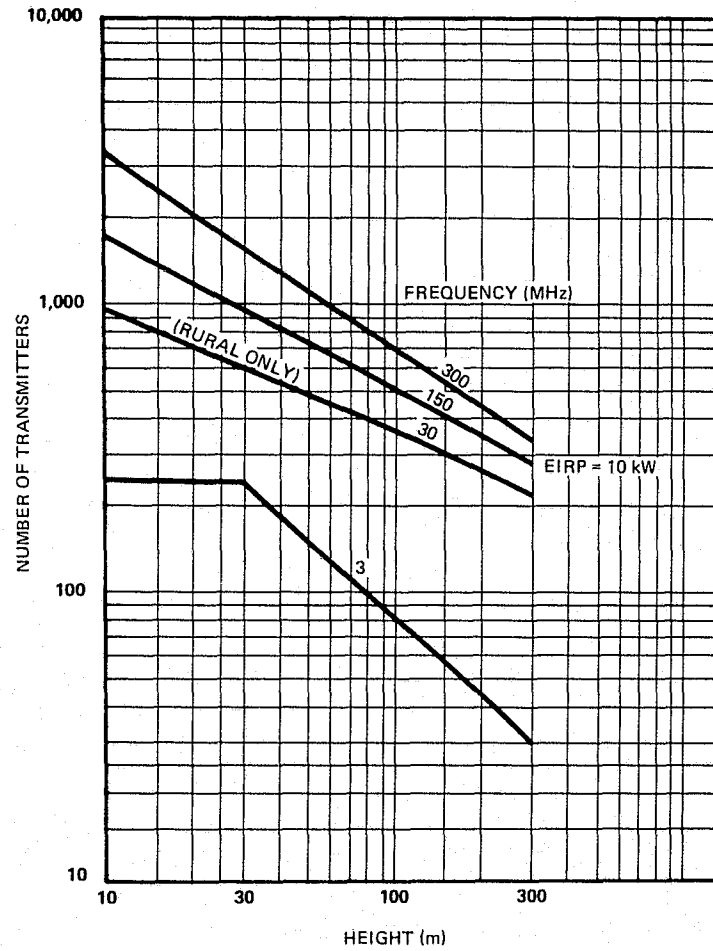


Figure 6-3. Number of Transmitters at HF/VHF (EIRP = 10 kW)

each LF transmitter. The baseband bandwidth requirement would then be approximately 40 kHz. Since high power LF transmitter/antenna system are narrow band, it is impractical to achieve the required bandwidths at LF.

6.3 TERRESTRIAL NETWORKS

The remaining three DWS functions, spotter reporting, data collection, and coordination are implemented primarily with terrestrial lines and are discussed in the following paragraphs. First, some of the general concepts of terrestrial networks applicable to the DWS requirements are discussed. This is followed by the specific configurations for the different functions.

6.3.1 General Concepts

A functional hierarchical structure for the DWS terrestrial network is shown in Figure 6-4. The five types of locations shown in the center of the figure (i. e., WSO, WSFO, NMC, WSMO, and RFC) require two-way voice communications and represent the highest level in the hierarchy. These locations must interface with each other as well as the other types of locations indicated. The arrows indicate the direction of traffic flow required to satisfy the stated NOAA requirements. The second level of the hierarchy includes the spotter headquarters, with two-way information flow to the types of locations indicated. Also included in the second level of the hierarchy are the news media and public officials each with one-way (receive only) information flow from the types of locations indicated. The third level includes the spotters, national organizations, and state officials who, from a functional viewpoint, must interface through the spotter headquarters. The spotters have two-way communications but the national organizations and the state officials have one-way, receive only communications.

Basically, there are two parallel types of services that could be used; common carrier networks or private line services. The available services are summarized in Table 6-1. Because of the reliability and "immediate access" requirements of the DWS, the common carrier service offerings are not considered to be suitable for the primary mode of operation. They will always be available as a backup mode should the primary system fail. Private line (dedicated) services are required to satisfy the DWS primary requirements. Four possible concepts are shown in Figure 6-5. From a reliability viewpoint, only multiple parallel lines as indicated in the second and fourth concepts are acceptable. Both are considered in subsequent paragraphs. A brief discussion of the reliability of terrestrial communications is given in Paragraph 6.3.2 and discussions of two possible methods of providing the DWS terrestrial hierarchy follow.

The interconnection (with multiple lines) of any two points in the hierarchy that have a community of interest (COI) is practical only when a switching network with automatic alternate routing is used. A Common Control Switching Arrangement (CCSA) is suitable for this purpose, but a dedicated DWS CCSA with the desired reliability

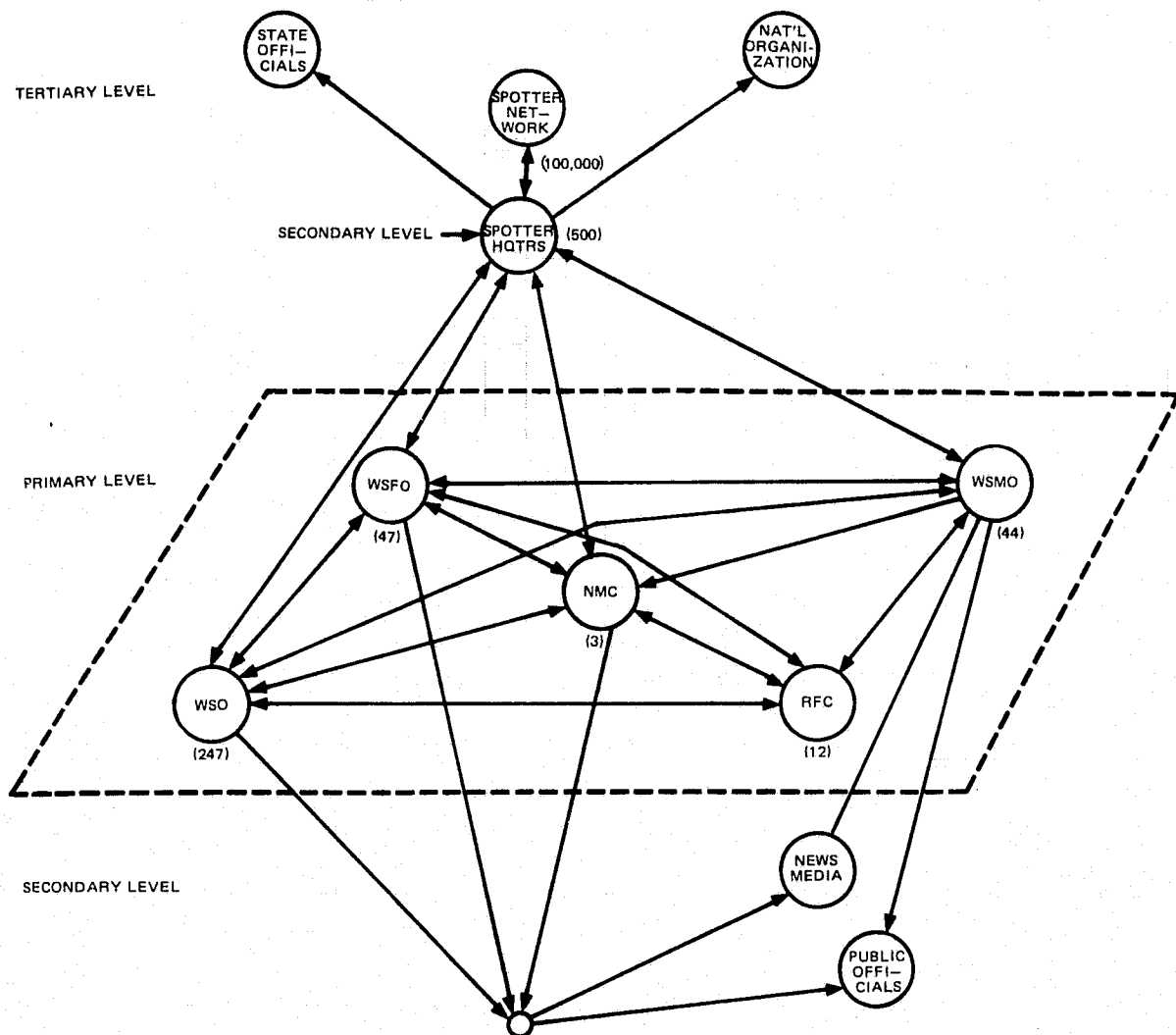


Figure 6-4. General Connectivity DWS Voice Network

Table 6-1. Terrestrial Communication Services

<u>VOICE</u>	COMMON CARRIER	PRIVATE LINE
Switched Network Services	<ul style="list-style-type: none"> • DDD Toll Service • WATS (DDD) • Short Period Service (DDD) 	<ul style="list-style-type: none"> • CCSA (AUTOVON, FTS) • Key Systems • Dial Tandem PBXs
Dedicated Private Lines	<ul style="list-style-type: none"> • - - - 	<ul style="list-style-type: none"> • Tie-Lines • Foreign Exchanges • Off-Premise Extensions
<u>DATA</u>		
Switched Network Services	<ul style="list-style-type: none"> • Dataphone (DDD) • TWX (DDD and Separate Network) • TELEX • DATANET 50 • Broadband Exchange • DATRAN Network • AT&T DDS • Other Data Networks 	<ul style="list-style-type: none"> • Private Message Switching Systems (e.g., AUTODIN, and ARS) • Multipoint Private Line Networks of Various Speeds
Dedicated Private Lines	-	<ul style="list-style-type: none"> • Analog Transmission Facilities Requiring Data Modems • Digital Transmission Facilities (Various Speeds)

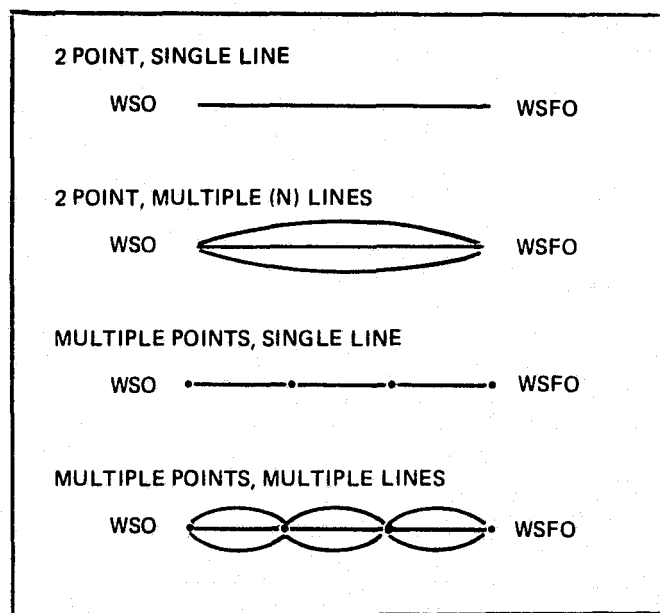


Figure 6-5. Alternative DWS Concepts

would be expensive. Probably a better solution for this type of configuration would be the use of DOD's existing Automatic Voice Network (AUTOVON) to provide DWS communications. Since AUTOVON has preemption and conferencing capabilities, this appears to be a practical solution even though it has other users. A discussion of the use of AUTOVON is presented in Appendix G.

Multiple points (DWS locations) connected in series in accordance with a pre-defined COI provide efficient use of transmission facilities, but such arrangements are vulnerable to outages since the loss of a single link could mean the loss of communications at several locations on that series circuit. Multiple lines, ensuring that each location has one or more alternate communication paths, greatly increase the system's reliability. A multiple point, multiple line, selective calling system concept recommended for the baseline terrestrial DWS is discussed in Paragraph 6.3.3.1.

A detailed system design requires the following information for each level of the DWS hierarchy:

- Types and locations of offices
- Community of Interest
- Interface requirements.

Appendix B to Reference 4 was used to determine the types and locations of offices.

6.3.2 Reliability of Terrestrial Communications

Generally, terrestrial communications system reliability can be affected by severe weather conditions, electronic equipment failure, power failures, sabotage, and enemy attack. The degree to which the system is affected depends on such factors as the amount of protection or hardening provided (if any) and where in the network the adverse condition occurs.

There are three types of transmission facilities used to establish circuits for private line and toll network applications. These facilities are defined by their areas of application. Each type has a different level of reliability due to its unique set of design specifications. The three types of transmission facilities by area of application are:

- Exchange (between serving central office and subscriber locations)
- Short Haul (between central offices in metropolitan areas)
- Long Haul (high volume long distance transmission)

These types are listed in order of increasing reliability. Dual routing can increase reliability significantly in the exchange area and in short haul areas if more than one route is available. However, in some areas only one route is available. In these

areas an alternate mode such as two-way radio could be used. A description of common carrier protection against long haul outages is provided in subsequent paragraphs.

The various long haul terrestrial communications systems are engineered with high degrees of reliability. Long-haul cable systems such as L-3 and L-4 installed since the early 1960s are generally buried underground and located to avoid target areas. These systems have varying degrees of hardness and blast protection which also makes them more reliable and survivable during a natural disaster. Other terrestrial systems such as the older cable (C and K carrier) systems are generally above ground and therefore less reliable/survivable during disasters and extremely bad weather. It is not uncommon for these cables to fall to the ground and become inoperative during heavy icing conditions or wind storms. These systems, however, represent a small percentage of the total long haul communications.

Some microwave relay radio systems such as TH, TL, and TM are subject to fading (loss of signal or "noisy" circuit conditions) during heavy fog and temperature inversions. Therefore, the common carriers do not use these systems where bad weather conditions frequently prevail. Generally, these severe weather conditions occur frequently in the Southeastern portion of the United States along the Gulf of Mexico coastal regions.

Automatic broadband protection switching is used in most of the long-haul terrestrial communications systems to significantly increase reliability. For example, in a 20-tube (transmission path) L-4 coaxial cable system, at least two tubes are not used for working circuits. (A tube has 3600 one-way voice equivalent circuits in an L-4 system.) The two one-way tubes are reserved as spares to be automatically switched into the system in the event that one of the working tubes in either direction fails for any reason. This automatic switching occurs in a few milliseconds and is undetectable in voice communications and causes only a minor hit (loss of a "few" bits) in data communications. Broadband protection switching is also employed on microwave relay radio systems, i. e., one spare broadband radio channel of five is reserved to be automatically switched into the system if a working channel becomes inoperative or noisy.

Automatic broadband switching will not help in the event of a total system failure. A total system failure can occur if a microwave tower is blown over in a severe hurricane or a cable system is severed by accident. In this case, the common carriers have comprehensive broadband restoration plans which must be manually implemented. Once a total system failure is detected it may take anywhere from a few minutes to several hours to completely restore all affected circuits in the failed system.

An important reliability factor that must be considered is that of power availability. The common carriers communications equipment is normally served by commercial power sources, but if commercial power fails, there is generally a standby battery supply with a minimum of 8 to 24 hours of reserve power. This standby

power is automatically switched into the system immediately upon the loss of commercial power. In addition to the standby battery supply, most major terrestrial communication systems also have diesel engine generators which automatically start when commercial power fails. Normally there is a 7-day supply, based on the knowledge that additional fuel can be provided if the commercial power outage lasts more than 7 days. Locations which have only battery reserve power are equipped so that a transportable diesel generator can be brought to the site to supply power prior to the battery reserve being exhausted.

6.3.3 DWS Hierarchical Structure for Voice

Typically, whenever a government agency requires leased dedicated lines, the service is obtained from the GSA TELPAK service. GSA purchases terrestrial line services for the government and then provides these services to government agencies at rates determined by GSA. In addition to the mileage charges, there are charges for connecting to the TELPAK, termination, and local loop charges. Unless there are additional capabilities other than the interconnection of dedicated lines, the network costs are determined from the mileage and number of end points.

6.3.3.1 Primary Level DWS Selective Calling Concept

This concept for the coordination requirement consists of all DWS primary locations connected together in party line loops each of which consists of a COI. Using selective calling features (dialing 3 or 4 digits), the network can be partitioned such that a preprogrammed number of locations are alerted to an upcoming message or, by using the broadcast mode such that all locations can be alerted simultaneously. Every network location would be programmed to respond to its own set codes which may include a unique code for each location. To minimize background noise, push-to-talk telephones are envisioned.

To enhance reliability, DWS locations are connected through a series of 10-way bridges. Thus, the loss of one leg of a circuit does not mean the loss of communications to all locations on the circuit. Bridging locations would be connected by two different routes (on Channels 1 and 2). Each terminal location could be homed on a primary and a secondary bridging location to further enhance reliability.

Terminal equipment would be selected to suit the environment in which it must operate. Push-to-talk telephones, speaker phones, and loudspeakers are options. Each site would be equipped with an auxiliary power supply in case of commercial power failure.

The selective calling network connectivity is illustrated in Figure 6-6. The network is divided into four regions with complete connectivity among the regional headquarters. Each of the regions contains several party line loops interconnected with each other and the regional headquarters by a switching network. Even though

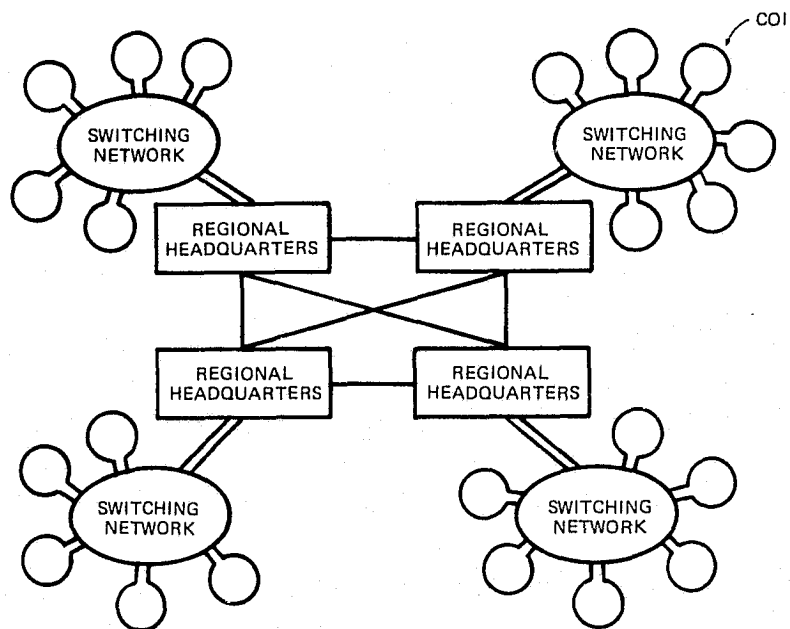


Figure 6-6. Selective Calling Connectivity

this switching network is illustrated as a central node, it actually exists as equipment located at the WSO users. Connected to each loop are from 10 to 15 WSOs chosen on common interest bases. Each loop consists of a single party line (plus a redundant line to enhance reliability) that has the capability for only one voice communication at any given time. However, calls in progress can be interrupted so that a self-contained priority system can be implemented. Calls outside a COI must go through the switching network. Once two (or more) loops are connected, they function as a single party line. If two loops are so connected, a third loop attempting to call one of these loops will receive a busy signal.

The estimated total mileage, including dual lines, is 123,430 miles. In addition to the standard cost, there is an estimated expense for the selective calling capability of \$250 per month per facility.

6.3.3.2 Secondary Level

The secondary level terrestrial network consists of dedicated lines from the WSOs to 500 spotter headquarters and 25 news media stations.

The 500 spotter headquarters will have full duplex voice communications to the two nearest WSOs. The estimated total mileage is 35,000 miles. The communication between the spotter headquarters and the spotters is via line-of-sight radio. Existing equipments are assumed for this function.

An estimated 25 news media interface locations throughout the U.S. will provide disaster warning information to the general public via TV and radio bulletins relayed from the major wire services. A complex terrestrial communications network currently exists between these news media facilities and the major wire services, and this study will therefore concentrate solely on interconnectivity between the primary level NWS stations and the 25 news media facility locations.

Each news media facility will be an estimated average of 175 miles from the closest WSO, with dual homing that average will increase to 375 miles for the two closest stations. The total mileage involved for all 25 news media facilities is 9375 miles.

6.3.3.3 Tertiary Level

The tertiary level must interface with the spotter headquarters, and includes state officials and national organizations in a terrestrial system. Since details of the destination locations are not presently available, assumptions and projections are made regarding the number of locations and their distances from spotter headquarters.

The estimated average mileage to the 500 national organizations is 30 miles for a total mileage of 30,000 miles for dual lines. The estimated average mileage to the

3000 local community officials is 50 miles for a total mileage of 300,000 miles for dual lines.

6.3.3.4 DWS Hierarchical Structure for Data

The general connectivity of the DWS Data Network is illustrated in Figure 6-7. Note that, with the exception of the links from the Reconnaissance Aircraft and the DCP which do not exist in the voice network, the connectivity is a subset of that shown in Figure 6-4. In other words, they are collocated with the voice locations. Thus, the transmission facilities used for voice can also be used for data. Two methods are practical:

1. The backup (dual-routed) voice channel can be used for transmitting the data. Data sets (modems), which cost about \$40 per month would be required at each terminal. The voice channel would serve as backup for data and the data channel would serve as backup for voice.
2. A bandpass filter can be used to obtain a telegraph grade transmission facility (about 150 Hz wide) from the voice grade facility without significantly degrading the voice circuit. The cost of such an arrangement is estimated at \$100 per terminal. Since the Reconnaissance Aircraft and Data Collection Platform transmissions are covered elsewhere in the study and not included in the terrestrial data communications, this \$100 per terminal represents the total data communications cost.

6.4 BASELINE TERRESTRIAL SYSTEM SUMMARY

The baseline terrestrial DWS uses broadcast transmitters of the NOAA VHF/FM type and dual-dedicated terrestrial lines for system reliability. The concept is illustrated in Figure 6-8. The system consists of three distinct networks: one which provides for disaster warnings, a second for spotter reports, and a third which services the data collection and coordination functions.

Using a geographical distribution of transmitters in a hexagonal pattern so that only three frequencies are necessary and a nominal coverage radius of 65 kilometers, approximately 750 transmitters are required to cover 99 percent of the population. Note that coverage is not provided to the ocean areas although extensive ocean coverage was included in the NOAA requirements. Extensive ocean coverage is generally incompatible with a terrestrial DWS. With 750 transmitters, there are an average of 2.5 transmitters for each WSO. Each transmitter has a coverage radius of only 65 kilometers, so that only two simultaneous transmissions per transmitter are necessary to meet the capacity requirements. The two voice channels are multiplexed onto a single carrier.

As illustrated in Figure 6-8, spotter reports are relayed to a WSO by a spotter control. Approximately 500 spotter controls are connected by terrestrial lines to the

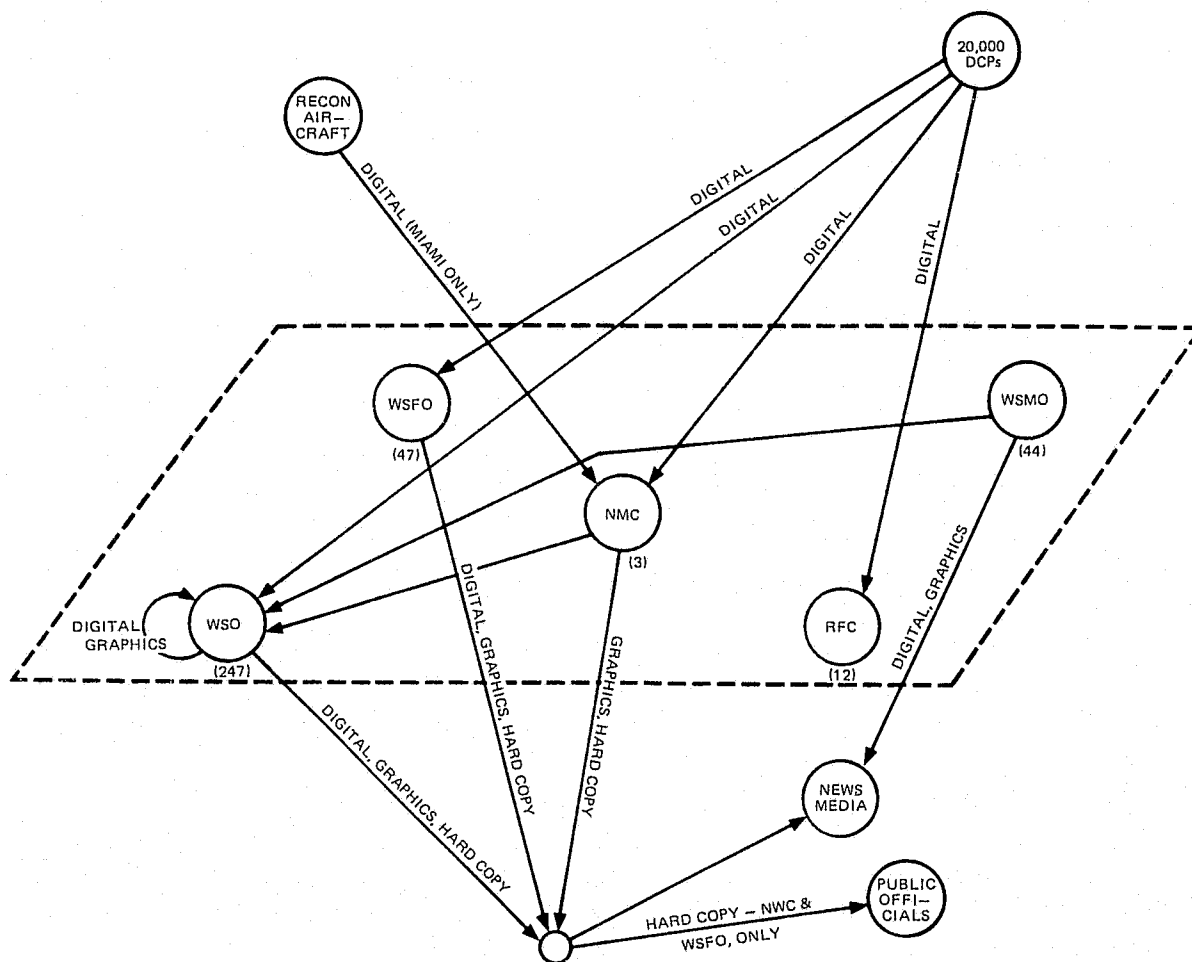


Figure 6-7. General Connectivity of DWS Data Network

two closest WSOs. Radio line-of-sight links (two-way voice) are used between the spotter control and spotters. Each spotter control can receive up to three simultaneous voice transmissions, the maximum number needed to meet the capacity requirement within an area covered by a WSO. The spotter control will be manned only as required and will be supplemented by volunteers. The manning and deployment of spotters will be in response to an alert.

The operational concept of the terrestrial line network for the coordination and data collection functions is illustrated in Figure 6-9. This network of lines, dedicated exclusively for the DWS, is divided into four regional areas, each of which contains a regional headquarters. Each regional headquarters is fully connected to the other regional headquarters. The WSOs within each region are grouped into communities of interest (COIs) which are interconnected by a switching network. The WSOs within each COI are connected by dual lines (one normally used as backup) acting as a party line. There is a selective dialing capability which connects either individual WSOs or a group of WSOs. Only one call per loop is possible at one time; however, ongoing calls can be interrupted. There is a self-control of the use of the party line. Calls between loops are established through the switching network. Once the call between loops is established, the two loops are connected and act as a single party line. If two loops are connected, a call from a third loop would get a busy signal. The switch provides some alternative routing capability for added reliability.

The data collection function is performed on the same lines as the coordination function. The separate line in Figure 6-9 is merely for illustrative purposes. The data is either sent when there are no voice communications or in a band just below the voice band. Two sources of data are indicated in Figure 6-9. One is from a remote sensor connected to a WSO by a terrestrial line; this data can be obtained by request from the WSO. The other source is via the GOES system; in this case the data must be requested from the National Meteorological Center.

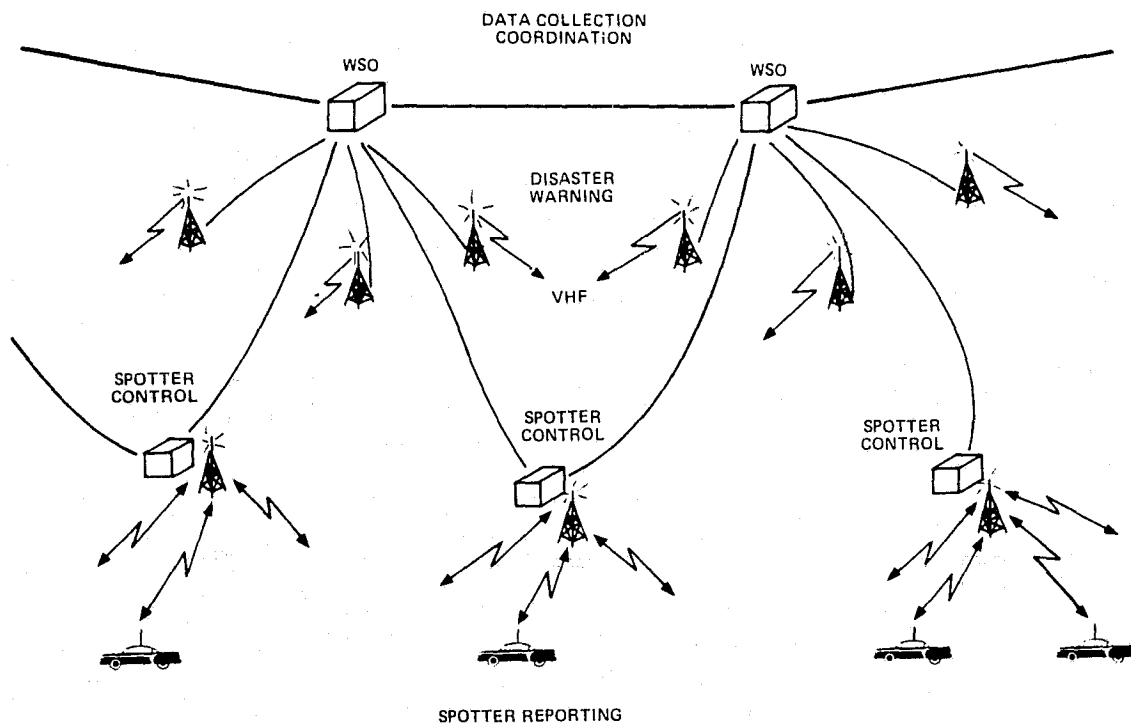


Figure 6-8. Terrestrial System Concept

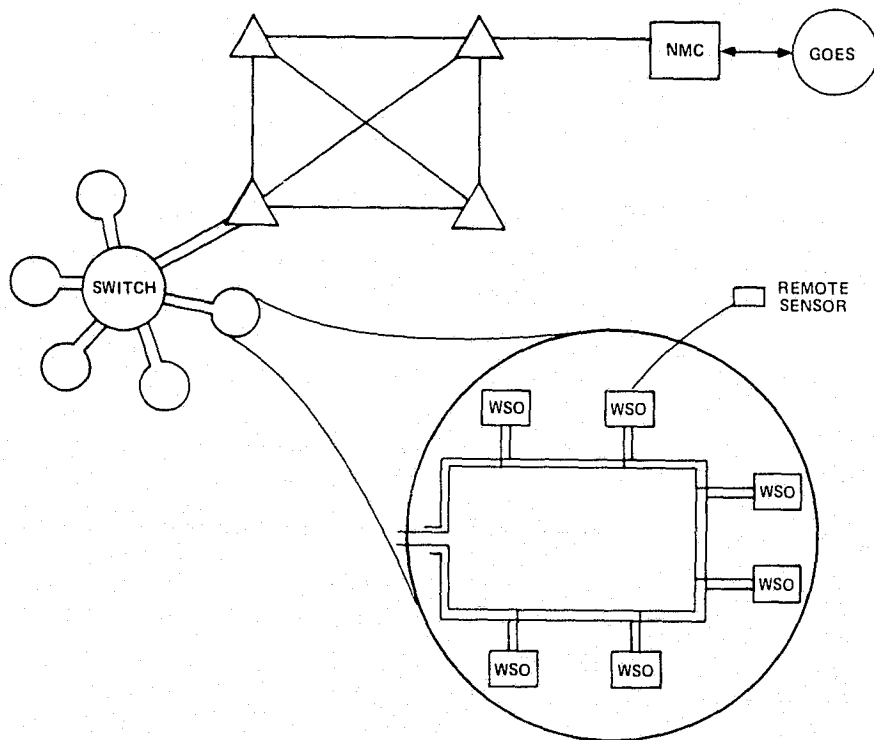


Figure 6-9. Coordination and Data Collection - Terrestrial

SECTION 7 - SATELLITE SYSTEM

7.1 INTRODUCTION

An alternative to a terrestrial DWS is a satellite DWS which utilizes geosynchronous satellites to relay information throughout the system 24 hours a day. Critical information such as disaster warnings can be broadcast via satellite directly from WSOs to the general public, public officials, and the news media. Likewise, spotters can be alerted and can report back to their respective WSOs via satellite. Voice coordination between WSOs, collection of data from remote sites by WSOs, and system control can be achieved with a satellite communications system. Constraints and tradeoffs of such system parameters are presented in this section and a baseline system is synthesized and described. A number of alternatives are synthesized and compared to the baseline system. Also, a hybrid system utilizing a mixture of both the satellite and terrestrial systems is discussed. Launch strategies for maintaining satellite system reliability are presented, and, finally, new technology requirements for a satellite DWS are given.

7.2 VOICE BROADCASTING

Voice broadcasting to the general public (homes), public officials, and the news media via satellite is a new technique which has certain advantages over others. In a disaster warning application, it can provide a reliability in the event of natural disaster which is better than that of most other types of communication systems. Additionally, it can more easily provide a wide area coverage than other systems. The use of a satellite system for voice broadcasts of disaster warnings is discussed in the following paragraphs.

7.2.1 Constraints and Basic Guidelines

To achieve effective broadcasting via satellite, the system must be designed under certain constraints and with some basic guidelines. One constraint is the required geographic coverage illustrated in Figure 7-1.

A single geostationary satellite located at 120° W longitude is in view of the entire area with no less than a 5° elevation angle. However, a single satellite would require a heavy on-board energy source to broadcast during an eclipse when the satellite is shaded by the earth. Thus, a second satellite that would not be eclipsed at the same time as the first is desirable, and would also improve system reliability. Two satellites must be separated by about 20° in longitude to avoid simultaneous eclipse. Normally, each satellite would provide communications to that portion of the coverage area that it could serve best. When one satellite is eclipsed, the second would take over all important coverage areas with a reduced system capacity. A third satellite would be required to reach the entire coverage area shaded in Figure 7-1 with continuous full system capability.

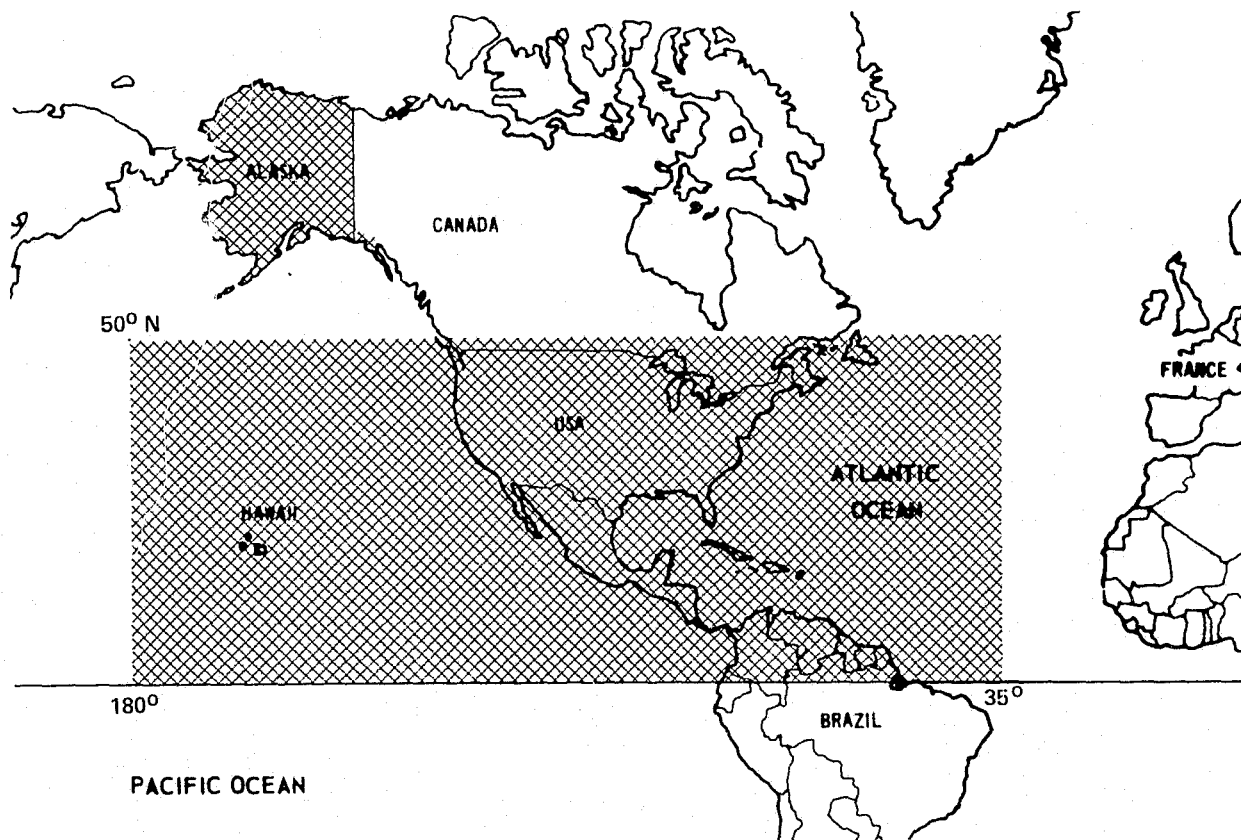


Figure 7-1. Geographical Coverage Requirement

Another constraint is the indoor location of home receiving antennas. Locating an antenna indoors with the radio set constrains the antenna to some practical indoor size and introduces additional signal attenuation associated with the building (assumed to be 15 dB in this study). Public officials, news media, high-rise apartments, and other heavily constructed buildings will have outside antennas.

To conserve satellite power, it is desirable to utilize home receiving antennas with as high a gain as is feasible. On the other hand, the receiving antenna must cover both satellites simultaneously. Furthermore, one cannot assume that the receiving antenna is accurately pointed, since it would not necessarily be installed skillfully. If the antenna should be pointed midway between the satellites and a pointing accuracy of 20 to 25 degrees is assumed, an antenna beamwidth of approximately 70 degrees is required to keep both satellites within the antenna's 3-dB beamwidth. Thus, regardless of the broadcast frequency, a beamwidth of approximately 70 degrees is desired with a gain of approximately 8 dB. Circular polarization is desirable to simplify orientation of the receiving antennas. Other constraints in synthesizing a satellite DWS arise from the system requirement.

7.2.2 Coverage and Satellite Antennas

The broadcasting area could be covered by a single satellite antenna beam or by multiple smaller beams. In either case, a particular broadcast message to one of the 20,000 different areas making up the entire coverage area would be transmitted on only one beam, the one covering that particular area. For multibeam, the antenna gain would be higher and less broadcasting power would be required than for a single beam. However, the satellite becomes more complex in other ways. As the number of beams increases, either more switching within the satellite is required, more channels are required, or both.

Several types of satellite antenna coverages are considered. Single beam and multibeam antennas with beams of circular cross-sections are considered. Also, numerous satellite locations were considered. In addition to the minimum 20-degree separation to avoid simultaneous eclipse, two other considerations were:

- Each satellite should provide coverage over the entire required coverage area.
- The Western satellite should be as directly south of Alaska as possible to minimize low elevation angles as seen from northern Alaska.

The chosen satellite locations are at 110° and 130° W longitude.

A single beam coverage, called northern hemisphere coverage, from each of two satellites is shown in Figure 7-2. The broken contours represent coverage from eastern satellite and the solid contours for the western satellite. The contours shown are 4.34 dB down from the antenna peak gain. This yielded an optimum beamwidth

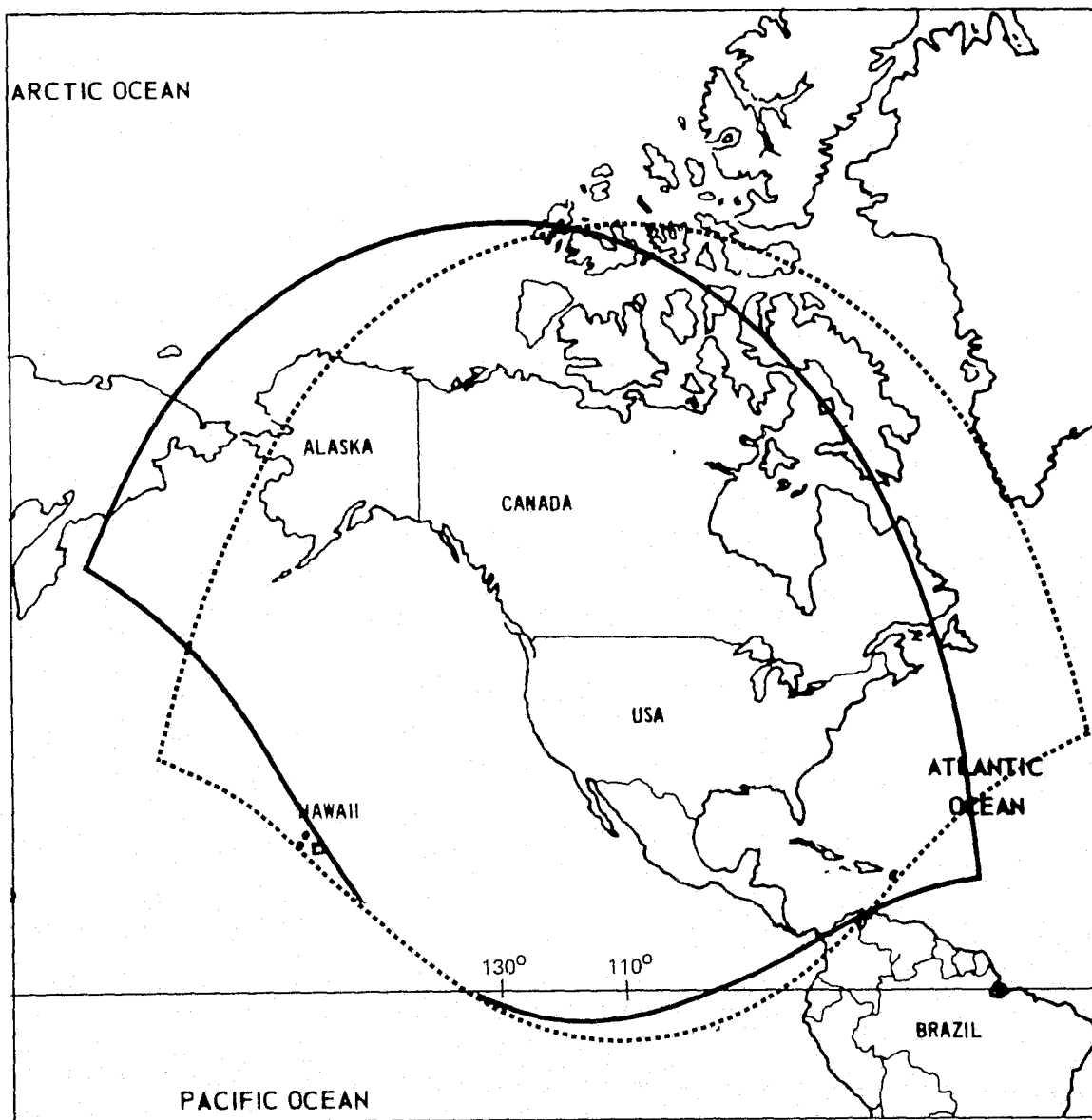


Figure 7-2. Northern Hemisphere Coverage From Satellites at 110° and 130° W Longitude

(Appendix H) rather than the half-power generally used. The corresponding half-power beamwidth is 11.6 degrees and the antenna gain 22.5 dB. These beams cover all land areas in the required coverage area and much of the ocean areas. A large portion of Canada, not in the required coverage area, is also covered with these wide beams.

Figure 7-3 shows an alternative spot beam coverage utilizing two satellites and five beams per satellite. The five beams cover five areas with one beam per coverage area as follows:

- Caribbean Area
- Eastern United States
- Western United States
- Alaska
- Hawaii

The number of simultaneous transmissions required for each beam is also shown in Figure 7-3. Large portions of the oceans are not covered, but all the states and the Caribbean area are. The broken contours represent coverage from the eastern satellite located at 110° W longitude, while the solid contours represent coverage from the western satellite located at 130° W longitude. Each satellite utilizes a single parabolic reflector with five different feeds to provide the five separate 2.95-degree half-power beamwidths corresponding to a nominal peak gain of 33.5 dB. The 4-dB contours are shown in the figure since they represent the assumed level of crossover from one beam to an adjacent one. Higher crossover levels do not appear practical from a design standpoint.

Covering essentially the same land areas as with the five beams, a 12-beam configuration is shown in Figure 7-4. Even though the satellites provide coverage with 10 and 11 beams, this alternative is designated for 12 beams since the coverage was derived from a 12-beam configuration. Again, the broken 4-dB contours represent coverage from the eastern satellite located at 110° W longitude, while the solid contours represent coverage from the western satellite located at 130° W longitude. Each satellite utilizes a single parabolic reflector with multiple feeds, each one providing a half-power beamwidth of 1.5 degrees. In this case the antenna gain is approximately 39.4 dB.

In each of the three antenna cases the off-axis design point is different. With a single northern hemisphere coverage beam the power at the edge of the coverage area is down 4.34 dB from that on axis. When five beams are considered, part of the coverage area is not within the contours, and one point in the United States is as much as 6.25 dB down from a point on the beam axis. In the 12-beam case the off-axis loss can be as large as 5.33 dB. These losses must be considered in calculating the power budgets for each of the three cases.

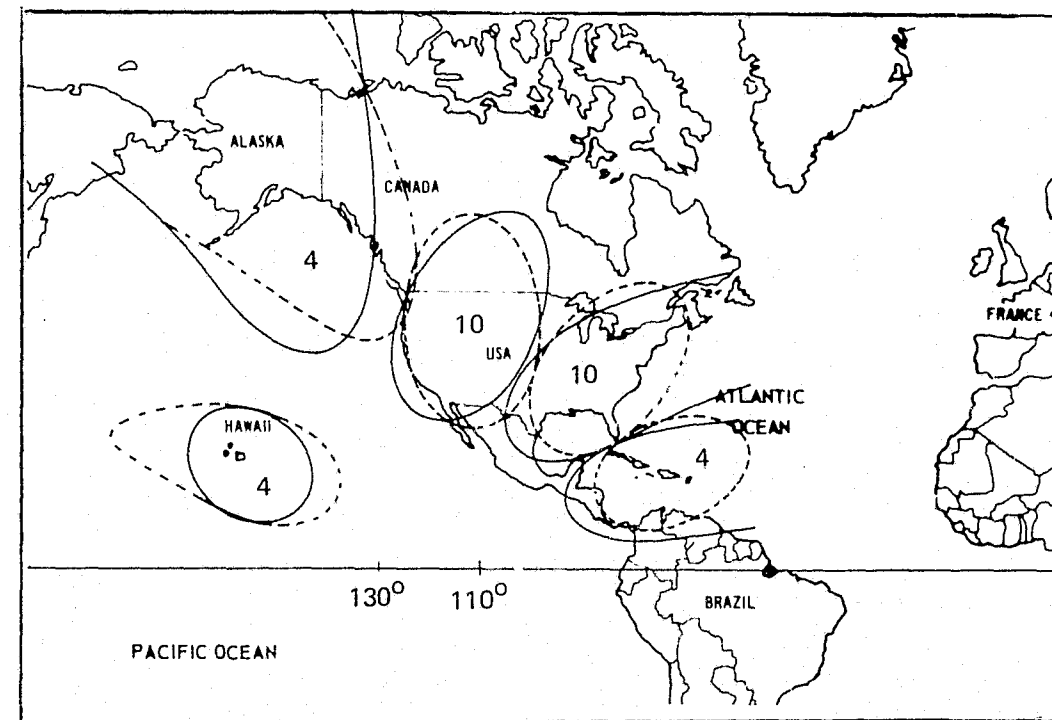


Figure 7-3. Five-Beam Average Patterns From Satellites at 110° and 130° W Longitude

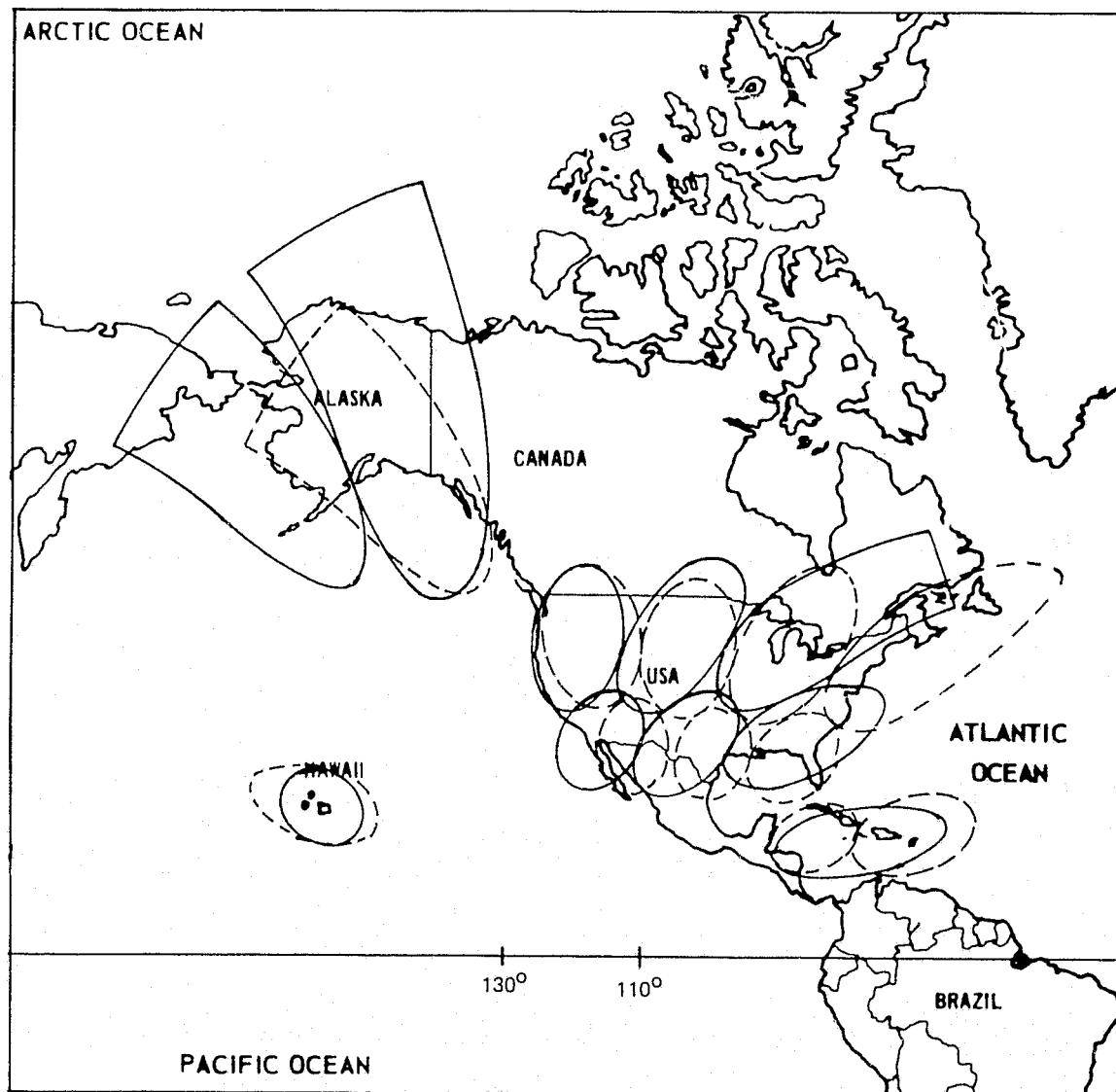


Figure 7-4. 12-Beam Configuration

The antenna parameters must be used in a tradeoff with other system parameters to attempt to optimize the system from a cost standpoint. A small antenna which covers a large area requires high power to reach home receivers, and high-power transmitters in space require considerable research and development. On the other hand, very large antennas, as would be required for the 12-beam configuration, can be used to provide large gains into spot beams and significantly reduce required transmitter power. The latter case requires a large number of beams and a very large erectable space antenna. The largest erectable space antenna developed to date is the approximately 9-meter parabolic antenna on ATS-F which has recently been operated successfully. Modest extensions to this technology could conceivably be easily made but much larger antennas would likely require a significant research and development effort. The best choice may be some intermediate combination of transmitter power and antenna size.

If all home receiving antennas are assumed inside and all other receiving antennas (public officials, news media, etc.) are assumed outside, the optimum types of coverage for each of these broadcasts will be different since the 15-dB allowance for building attenuation is significant. Thus, home broadcasting is referred to as high-power broadcasting and the other is called low-power broadcasting. The multi-beam coverage looks attractive for the high-power broadcasting and the single-beam coverage for low-power broadcasting.

7.2.3 Frequency Choice

The broadcasting frequency is chosen to minimize costs under system constraints. This choice is based to a large extent on potential satellite broadcasting bands and RF attenuation factors.

The frequency bands considered for this application are the three designated as satellite broadcasting bands by the 1971 World Administrative Radio Conference (WARC). These bands are:

- 620-790 MHz
- 2.5-2.69 GHz
- 11.7-12.2 GHz

The preferred band is the one which would result in the least expensive system. Perhaps the best criteria for choosing a frequency band is that which requires the least satellite power and results in simple low-cost home receivers.

There are several attenuation factors which affect the choice of frequency. These attenuation factors are:

- Rain Attenuation
- Building Attenuation
- Free Space Loss

Since the satellite antenna gain is defined by its coverage area and the ground antenna gain is defined by its satellite coverage and pointing accuracy, the required satellite transmitter power is directly related to the losses.

Figure 7-5 shows the attenuation caused by rain for a rate of 100 mm/h and for four receiving antenna elevations. This rain rate occurs with a probability of approximately .0045 in high rainfall areas.

The attenuation is higher at low elevations than at high elevations. For an elevation of 5 degrees the attenuation varies from 0.1 dB at 2 GHz to approximately 50 dB at 12 GHz. Thus, rain attenuation is negligible in the lowest WARC band, perhaps as high as 0.4 dB in the mid-band and approximately 50 dB in the top band. Clearly, the highest band is not practical for this application, since extremely large satellite power levels would be required to overcome the rain attenuation in that band. Thus, consideration of rain attenuation limits the investigation to the two lower frequency bands.

Building attenuation is also critical to the system. There have been several efforts at measuring building attenuation, each time with specific frequency bands in mind for a particular use. The FCC made attenuation measurements on television channels 2, 7, and 31 for various types of structures (Reference 7). The data showing average losses are shown in Figure 7-6 for various structures.

Data points for each type of structure are connected by straight lines which are extended for extrapolation of the data. These data show a general trend of increasing attenuation with frequency. Some other measured points are also included in the figure. The BBC data for ground floor measurements tend to agree with the FCC data. Other data points are shown for the first floor of city buildings. The FCC data show average building attenuations ranging from 17.5 dB for wooden structures to 28.3 dB for reinforced concrete in the lowest potential broadcasting frequency band (620-790 MHz). Although the FCC data indicate increasing building attenuation with frequency, there does not seem to be any building attenuation data available at frequencies above 1 GHz to confirm or reject this hypothesis. However, there appears to be no reason to expect that building attenuation decreases at higher frequencies. Minimizing building attenuation thus appears to favor choosing the lower frequency band.

The National Bureau of Standards measured building attenuation at 180- and 750-MHz (Reference 8) for various types of buildings. The statistical results of the measurements at 750 MHz for all buildings are shown in Figure 7-7) and generally

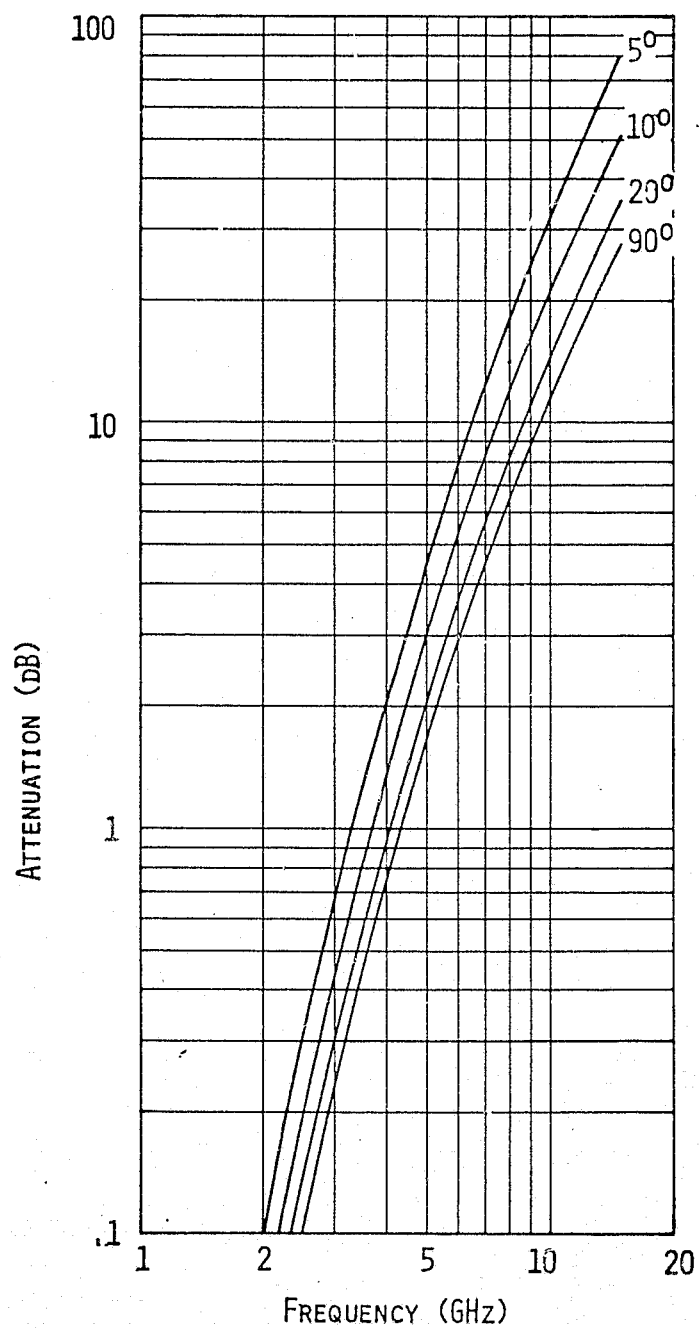


Figure 7-5. Rain Attenuation for a Rain Rate of 100 mm/h and Several Receiving Antenna Elevations

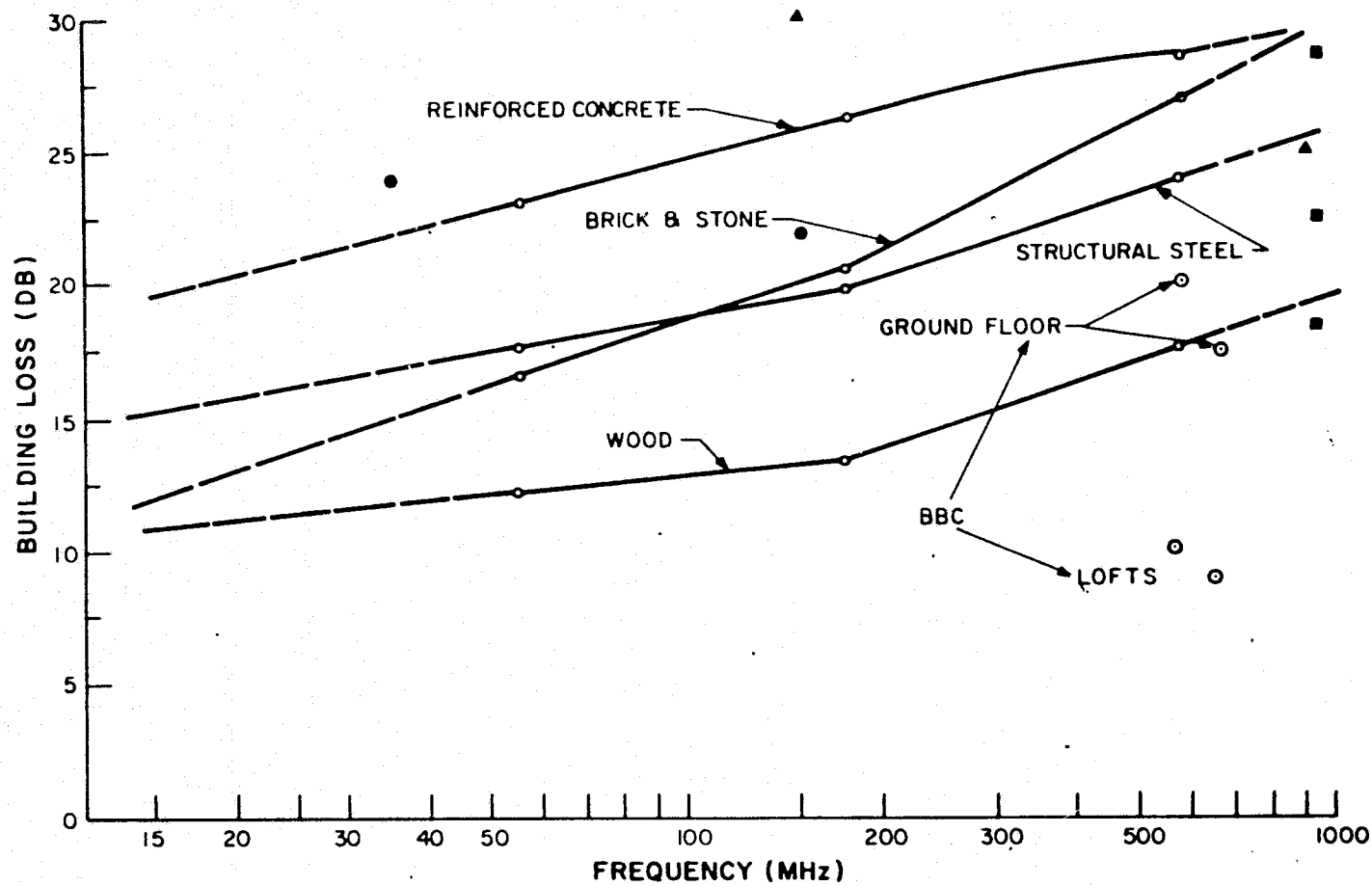


Figure 7-6. Building Attenuation for Various Structural Types as a Function of Frequency

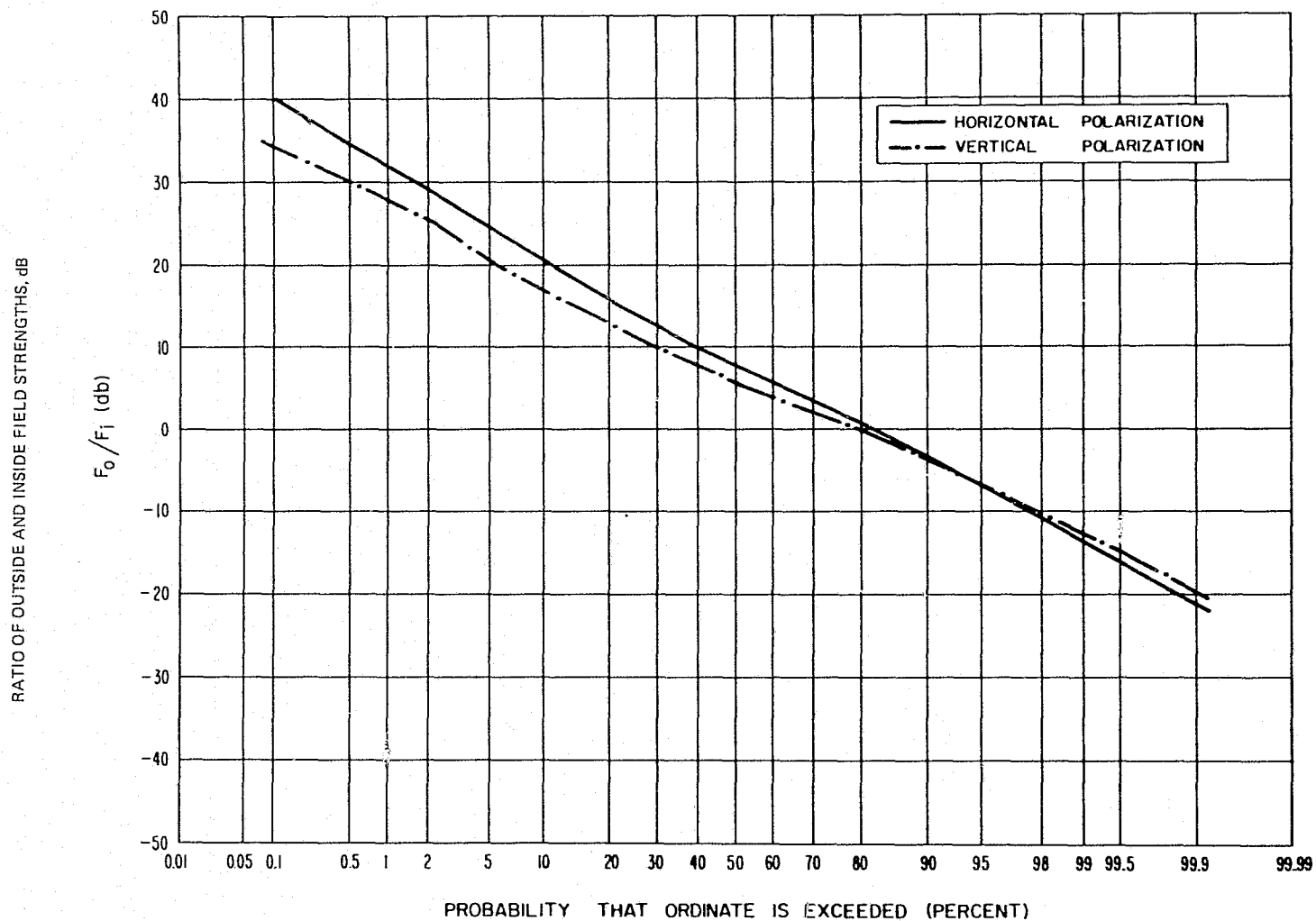


Figure 7-7. Distribution of Difference in Outside and Inside Field Strengths
for All Buildings Examined at 70 MHz

agree with the FCC data. Based on these results, 15 dB for the 620-790 MHz band was assumed for building attenuation.

Free space loss varies inversely with the square of the frequency, thus favors the lowest frequency band. The free space loss is given in Table 7-1 for frequencies in each of the three WARC bands. Note that the free space loss at 790 MHz is 10.3 dB lower than at 2.6 GHz. Therefore, it would take 10.3 dB less satellite transmitter power to operate at 790 MHz than at 2.6 GHz just on the basis of free space loss and with the same antenna gains.

Table 7-1. Free Space Loss at 45° Elevation

Frequency	Loss
790 MHz	181.9
2.6 GHz	192.2
12.0 GHz	204.5

In conclusion, the lowest WARC broadcasting frequency band was chosen to keep the satellite power at a reasonable level. Clearly, higher frequencies are not desirable. Frequencies significantly lower are not desirable either, because environmental noise begins to degrade reception and the antennas on both the satellite and home receivers would get rather large without a corresponding increase in gain.

7.2.4 Transponder Configuration

Some of the factors that influence the satellite transponder configuration are the required coverage area, requirement for indoor reception, number of channels, RF power levels, operating frequencies, and transmitter power. The following paragraphs discuss the effects that various requirements and parameters have on the transponder configuration.

The required coverage area is rather large, and therefore requires one large beam or several smaller ones. If a single beam is used, a large amount of RF transmitter power is required for high-power broadcasting because the antenna gain is low (22.5 dB) and building attenuation must be overcome for indoor reception. If several beams are used, then, for any one beam, the antenna gain can be increased with a corresponding decrease in the beam. Some additional reduction in beam power may be realized from using multiple beams by the fact that beam spillover outside the required coverage area is less, thus resulting in a more efficient coverage pattern. A single switchable narrow beam is not satisfactory, because it must transmit ten simultaneous warnings to different parts of the coverage area.

If multiple beams are used for high-power broadcasting, it would seem reasonable to utilize these same beams for uplink signals. If the same frequency band is used for uplink signals, the satellite uplink coverage is approximately the same as the downlink coverage and the same antenna might appear practical for both uplink and downlink. Two problems arise in this application. First, the uplink and downlink frequencies are closely spaced; therefore it is difficult to provide sufficient isolation between the transmit and receive channels. Second, there is an additional multiplexing loss in the high-power transmission line, making the required high level of RF transmission power even more difficult to achieve at the antenna. If the uplink frequencies are in a different band from the downlink frequencies, to make isolation of the signals easier, the uplink and downlink antenna coverages are different. If the uplink frequency is somewhat higher than the downlink frequency, as is often the case, the coverage area would be less than desired. In conclusion, it appears best to use a separate uplink antenna from the downlink antenna, particularly since the uplink does not have the same magnitude of communication difficulty.

The number of separate RF transmitting channels in the satellite transponder depends on the transmitter power required for each carrier and possibly on the number of separate beams, if spectral usage is a critical consideration. If the carrier power is relatively low on all channels, it is practical to use a single transmitting amplifier to linearly amplify all the carriers simultaneously. On the other hand, if the carrier powers are high, a very high power transmitter is required for linear amplification. The efficiency of a high-power linear amplifier is also rather low. Nonlinear operation causes intermodulation interference and, therefore, the amplifier of multiple signals may well have to be operated at some point well below the saturation level.

If a single transmitter is used for multiple carriers, the signals must be separated into their respective beams if more than one beam is used. This is based on the practical assumption that all signals are not transmitted on all beams. If they were, there would be no advantage of multiple beams other than possibly beam-shaping a single beam. Separation of the signals at the RF transmission frequency means high-power demultiplexing and may result in large spectral utilization. The spectral usage is dependent on the minimum frequency separation of the carriers required for demultiplexing. Suppose, for example, the five simultaneous carriers are amplified together and are separated into five beams. If the carrier frequencies are at approximately 800 MHz and if the multiplexer cannot effectively separate carriers closer together than 0.5 percent the carriers will be at least 4 MHz apart and the five signals will occupy 16 MHz or more. If fewer channels are required, the spectral utilization improves significantly.

Another possibility is the use of one transmitter for each beam. For DWS, this does not solve the problem of multiple signals in a single amplifier, because all signals may be on a single beam at one time.

The number of transmitters could be the same as the maximum number of carriers required. This would require less spectral usage than those configurations requiring multiplexing or demultiplexing at the RF transmission frequencies. If there are several frequencies and several beams, the high power switching and multiplexing becomes rather lossy and complicated for placing any combination of carriers on any of the beams.

One solution to the problems associated with the alternatives for high-power broadcasting is to allocate enough carriers to each beam to handle all traffic required in that beam. In this way, each carrier can have its own transmitter which will be used only when that carrier is activated. RF multiplexing of all carriers associated with each beam is required, but no high power switching is required. This technique does not solve the spectral problem, but it does handle high power in a channelized sense with high reliability.

In contrast with the channelization problems associated with the high-power broadcasting, it appears feasible to use a linear transmitter with all FDM/FM channels amplified simultaneously for low-power broadcasting. This is true if the number of channels is not excessive.

One broadcasting technique which reduces the required number of carriers is the use of demodulation and baseband multiplexing in the satellite to put all voice channels of a particular antenna beam on one downlink carrier. Each uplink voice channel utilizes a separate FM carrier which is demodulated in the satellite. The voice channels intended for a particular antenna beam are multiplexed and the resultant composite baseband signal frequency modulates a single carrier. A single saturated high-power amplifier amplifies the carrier which is finally directed toward the earth via a single antenna beam. Similarly, a single multichannel carrier is used on each of the other beams. For a five-beam case, there are five separately amplified FM carriers, each with multiple voice channels. An obvious advantage of this system is the use of only five high-power amplifiers, each of which amplifies a single carrier rather than a high-power amplifier for each voice channel. Also, no lossy multiplexing is required between the high-power amplifier and the antenna and the number of carrier frequencies is reduced.

On the other hand, there are some disadvantages of baseband multiplexing in the satellite. Every channel must be demodulated in the satellite and those intended for a particular beam coverage area must be multiplexed for remodulation of a single carrier. In addition to all of this signal processing, which may reduce satellite reliability, the reliability is further reduced because failure of a single FM channel results in catastrophic failure, the loss of an entire antenna beam. When multiple carriers utilizing separate high-power amplifiers are used, the system can degrade gracefully with only a reduction of the number of carriers available in a particular beam and without the loss of all channels.

Comparing the two transmission techniques shows that less RF power is required when a separate carrier is used for each voice channel rather than a common carrier. Figure 7-8 illustrates this comparison by presenting the power required as a function of the number of voice channels for the two techniques. The RF power is normalized to that required for a single channel FM carrier. The FDM curve in the figure shows the relative total RF power required when additional channels are occupied by the addition of FM carriers. For example, twice as much RF power (3 dB more) is required if two single-channel carriers are used. If a single five-channel carrier is used, it requires approximately 8.8 dB more power (as illustrated in the figure) than a single channel carrier, regardless of the number of occupied channels. If two five-channel carriers are utilized to provide 10 voice channels, the power increases by 3 dB above that for a single five-channel carrier. If at least one of the channels of each carrier is occupied, the power required to support 10 channels is as shown in Figure 7-8. In all cases, less power is required to support a given number of channels if the FDM technique is used. When five channels are used on a five-channel carrier, the radiated RF power required is approximately 1.8 dB more than the total required for five single-channel carriers. The difference may be somewhat less than 1.8 dB at the transmitter, when FDM multiplexing losses are considered. As a good approximation, an m -channel FM carrier requires m times as much transmitter power as a single channel FM carrier. This technique is not attractive for the DWS application primarily because of the extremely high satellite prime power required.

7.2.5 Receiver Demuting

Every receiver must have a demuting capability for receiving a message on any of its ten available channels. These channels cannot be used for demuting, since they are required for broadcast reception and would not be available for reception if one or more were used for demuting. The receiver must be tuned to a demuting channel at all times, at least when it is not already receiving a broadcast message. Thus, an eleventh channel must be used for demuting. If the demuting channel is FSK, the data rate can be low enough so that a high-power demuting transmission is not required. In fact, a single channel on a wide-coverage beam could be used for demuting all receivers. The demuting signal could be directed uplink to the satellite best covering the receivers to be demuted, just as the voice broadcast messages are.

To simplify the receiver design and keep its cost to a minimum, the demuting frequency should be chosen in the same band as the voice broadcasts. These demuting considerations apply to low-power as well as high-power broadcasting.

Demuting broadcasting receivers must be done with some specified reliability and with minimum complexity and cost. Here, the effect of coding, which complicates the receiver and lowers satellite power, is considered. The constraints of this analysis are:

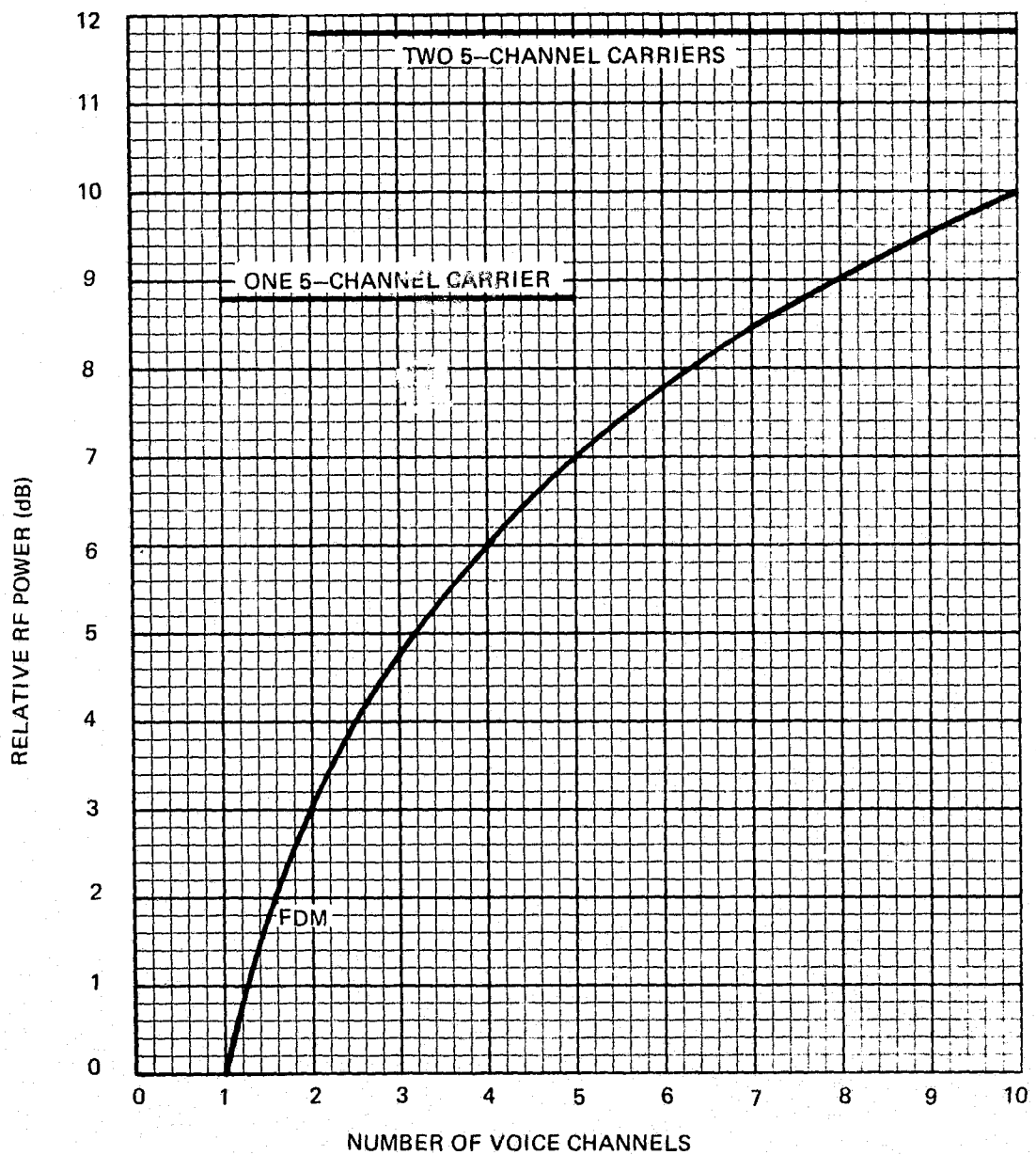


Figure 7-8. Comparison of RF Powers Required For Five-Channel And Single-Channel Carriers

1. The probability of turning on a particular receiver when its address is not sent does not exceed 10^{-10} .
2. The probability of not turning on a particular receiver when its address is sent does not exceed 10^{-7} .

Since there are approximately 60,000 different addresses to be considered, there must be 16 bits in the address. If the address is coded, additional binites will be used to convey the 16 bits of information. Three different cases are considered:

1. No coding is used; i.e., a (16,16) sequence of 16 binites carries the 16 bits of address information with no error detection or corrections.
2. A (21,16) code is used; i.e., a sequence of 21 binites is used to transmit the 16 bits of address information. This code has the capability of 1 bit of error correction or 2 bits of error detection.
3. A (26,16) code is used; i.e., a sequence of 26 binites is used to transmit the 16 bits of address information. This code has the capability of 2 bits of error correction or 4 bits of error detection.

Figure 7-9 shows the required satellite EIRP as a function of the information bit rate. The uncoded (16,16) case requires approximately 4 dB more satellite EIRP than the (26,16) case and approximately 3 dB more than the (21,16) case. These graphs account for the 15 dB margin for building attenuation. They are helpful in determining the usefulness of coding and the operation point of the system, which are determined by the delay times allowed.

7.3 SPOTTER COMMUNICATIONS

To provide information required for disaster warnings, spotters are necessary for reporting disaster information from locations near disasters or potential disasters. A report from any one of 100,000 police, fire, civil defense, and local authorities must be transmitted to a WSO* or other stations for analysis and as a basis for issuing warnings. Some constraints and basic system guidelines are presented and some technical considerations are discussed.

7.3.1 Constraints and Basic Guidelines

The system must first provide some way of alerting the spotter, while he is at home, asleep, or at some other particular location. It is assumed that the spotter's receiving antenna for the alert is not within a building, but outside, to avoid the attenuation associated with the building. After the alert, the spotter travels to his assigned

*Throughout this and the following paragraphs, WSO is used as a general reference to any of the NWS facilities that require DWS transmit and receive capabilities.

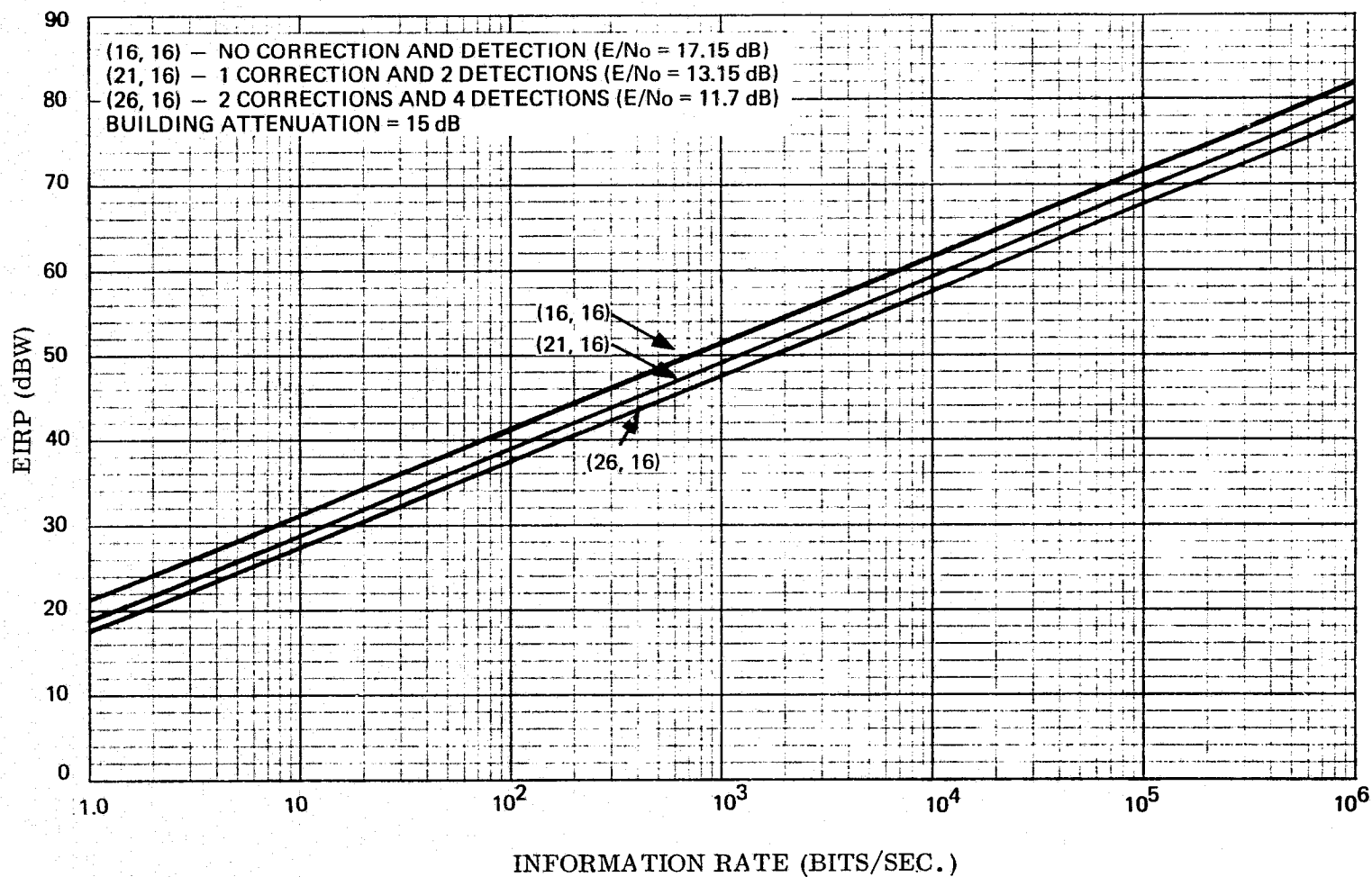


Figure 7-9. Effective Radiated Power Required To Demute Broadcast Receivers As A Function Of The Transmitted Information Rate for a 790-MHz Carrier

observation area, if he is not already there. When he observes events relating to potential disasters, he reports them via a half-duplex voice channel which the system is required to provide. The satellite system must be able to handle 50 of these half-duplex channels simultaneously.

The capability of the user to point his antenna has a definite impact on system design. It is assumed that the spotter will be able to point his transmitting antenna within 15 degrees of the satellite he is supposed to use. The size of the antenna that the spotter uses for reporting is limited because of its required mobility. It may be used on police cars and other vehicles as well as on fixed structures. A maximum diameter of 0.5 meter is assumed.

7.3.2 Link Considerations

The link between the spotter and the satellite is the critical link, while the link between the satellite and a large ground terminal at a WSO is not as critical. For this reason only the first link will be treated here. The assumed antenna pointing accuracy of the spotter is 15 degrees. If this corresponds to the 4.34 dB off-axis angle (see Appendix H), the half-power beamwidth is 24.9 degrees and the gain is approximately 14.8 dB. Thus, 14.8 dB is the maximum allowable spotter antenna gain as a result of pointing accuracy. The satellite antenna is constrained by the coverage area as in the broadcast case and its gain will be thereby determined.

The best frequency to use is the one which provides the maximum power transfer within system constraints. Attenuation by rain is negligible for frequencies below 2 GHz (see Figure 7-5). Therefore, any frequency of 2 GHz or less would be acceptable. If one assumes that the spotter has a fixed antenna size and that the satellite antenna is of fixed gain, the link power transfer is independent of frequency except for small losses not attributed to spreading of the signal in space. To maintain constant coverage, the satellite antenna size decreases with increasing frequency; therefore, the highest frequency within the constraints is desirable to minimize the satellite antenna size. The highest frequency satisfying these constraints with a 0.5-m antenna is 1.6 GHz. If the antenna size were 0.4 m, rather than 0.5 m, the highest frequency would be 2 GHz. Since the satellite will have a northern hemisphere coverage antenna operating in the neighborhood of 2 GHz for the data collection application, it would be convenient to also use that antenna for the spotter communications at some frequency in the range from 1.6 to 2 GHz.

7.3.3 Communications to Spotter

The spotter alert is much the same as the disaster warning voice broadcast to public officials and the news media, because the spotter's receiving antenna is outside to avoid building attenuation. Therefore, low-power broadcasting channels can be used to alert the spotters. The spotter would use a receiver like those used for the general public except that the antenna would not be indoors and the addresses would be different. Each spotter would have a distinct address so that he could be contacted independently of all others.

The 50 half-duplex voice channels for communications between the WSOs and the spotters are difficult to implement, particularly the downlink portion from the satellite to the spotter. Implementing this downlink is basically the same problem as implementing low-power broadcasting channels, except that the power required for 50 simultaneous channels becomes extremely large compared with the high power already required for the broadcast channels.

A practical alternative to satisfying the WSO-to-spotter communication requirement is to relax the requirement and use only a few low power broadcasting channels for WSO-to-spotter communications. Although it may sometimes be necessary to communicate with the spotter, it is most important to get a report from him. Imposing a standard half-duplex requirement on all 50 channels does not appear to be practical.

7.3.4 Communications From the Spotter

In contrast to the WSO-to-spotter portion of the 50 required half-duplex voice links, 50 spotter-to-WSO links are feasible. Before reporting his observations to the WSO, the spotter would first point his antenna toward the proper satellite and then transmit his observations to the WSO on an assigned channel. Some type of system control is required for the assignment of channels; this is discussed in Paragraph 7.6.

Fifty channels is so cumbersome that a channelized repeater is not practical; therefore, all signals are amplified together in a single satellite transmitter. The transmitter must be reasonably linear to avoid interference of intermodulation products. This method can result with a relatively inefficient transmitter.

Before transmitting a message, the spotter must somehow get a channel assignment. This assignment cannot be made in advance, because it is not possible to predict when the channel would be needed. If an advance assignment were made, the channel would be idle until the spotter needed it; not an efficient use. A random access channel by which spotters could make channel requests seems appropriate for this application. This could be done digitally.

7.4 VOICE COORDINATION

Five full duplex voice channels were assumed to be required for coordination between the WSOs (no specific channel requirements were specified by NOAA). There are actually ten simplex links required in the system to make up the required five full duplex links. Each WSO is required to transmit on any one of five channels and receive on one or more channels. Simultaneous reception of multiple downlink signals is useful for conference calls among several WSOs. The capability of receiving one's own transmission could be useful as a check of the system's operations. The voice coordination signals would be of a low enough level in the satellite transmitter that all

of them could be amplified together in a linear transmitter and beamed downward in a single northern hemisphere coverage beam. A single northern hemisphere coverage could also be used for the uplink.

The uplink and downlink frequencies are not critical from a signal level standpoint, because the WSOs can have transmitting and receiving subsystems of respectable EIRP and quality that minimize the impact of the frequency choice. Rather, the frequency choice for this application should be based on its relation to frequency bands and equipment required for other system applications. By common use of frequency bands, antennas, and other equipment, the system cost can be more easily minimized.

7.5 DATA COLLECTION

The system is required to provide communications for data collection from approximately 20,000 data collection platforms (DCPs) located in remote areas of the United States and offshore in the adjacent oceans. Data must also be transmitted from hurricane reconnaissance aircraft to the NHC in Miami. Two hundred channels are required to transmit data from the DCPs during normal times and 200 are required to transmit data from the DCPs during disasters.

This does not necessarily mean that 400 channels will be required for the DCPs, but some number between 200 and 400. Five simultaneous channels are also required for the hurricane data.

A system presently exists for the collection of data from DCPs via satellite. The transponder for the present system is on the recently launched SMS/GOES satellite. Data collection platform radio sets (DCPRSs) and command and data acquisition (CDA) stations have been built for use in this system. To continue the data collection function of the present system would require use of the DCPRSs unless the entire system were redesigned. It would therefore seem wise to utilize the same DCPRSs in the DWS. Only 150 channels are allocated for domestic use in the present system (33 additional channels are allocated for international use). Therefore, more channels would have to be allocated to fulfill the DWS requirements. The new system would only be an extension of the old system, utilizing the same techniques but with more channels, a different satellite transponder, and receiving terminals. Data in the new system would be received directly by the local WSO in addition to the CDA station. The same DCPRSs could be used to relay the hurricane data from the reconnaissance aircraft via satellite to the NHC in Miami.

Since the data rate in the system is only 100 bits per second, the bandwidth is narrow and relatively little RF power is required. The signals can be multiplexed in the satellite and amplified simultaneously in a linear transmitting amplifier. Because of the low power requirement, the uplink and downlink antennas can be broadbeam antennas. No special satellite difficulties are anticipated.

7.6 SYSTEM CONTROL

A satellite communication system which can be accessed by any of 300 ground broadcasting stations and by any of the 100,000 spotters must have some type of system control, since the satellite capacity is much too low for the simultaneous access of all these users or for their random access. There must be some kind of assurance that two WSOs do not broadcast simultaneously on the same frequency, that two spotters do not report simultaneously on the same frequency, or that similar difficulties do not occur during normal system operation. Some type of centralized automated control appears to be the most logical way of exercising system control. A central control station (CCS) would be a logical approach.

With the CCS concept, the WSOs would make their requests to the CCS for communication channels and the CCS would respond with channel assignments according to availability. A time division access (TDA) channel could be used for communication from the WSOs to the CCS, and a second TDA channel could be used for communication from the CCS to the WSOs. Although a single channel would provide sufficient capacity for communication in both directions, a second channel would reduce the time delay of the CCS response. Similarly, a third (random access) channel, would be used to enable a spotter to request a channel for reporting to his local WSO. A fourth channel would be used for the CCS to make the channel assignment simultaneously to the spotter and to the local WSO.

The TDA channel from the WSOs to the CCS has a frame with 300 time slots. Each time slot corresponding to a particular WSO consists of a preamble followed by information bits. An estimated number of binitis is shown in Table 7-2. Here, a preamble of 85 binitis is followed by 111 information bits. If the information is coded for a 4 bits ($t=4$) of error correction, another 32 binitis are required, making a total of 228 binitis per WSO time slot. Since there are 300 WSOs which must communicate their requests to the CCS, the number of binitis transmitted per time frame is 68,400.

Similarly, the CCS response channel to the WSOs is a TDA channel with 300 time slots per frame. Each time slot, corresponding to a particular WSO, consists of a preamble and information bits according to the proposed allocation shown in Table 7-3. Three hundred time slots, each of 148 binitis, requires a total of 44,400 binitis per frame.

If one assumes that a 10-second frame time is acceptable, a WSO must transmit at a rate of 6840 binitis per second and the CCS must transmit at a rate of 4440 binitis per second. These control channels can utilize separate satellite transmitters to achieve maximum efficiency. The frequencies should be in bands already required in the satellite, since the antennas can be shared easily for different functions if the frequencies are compatible and in a common band. These channels would not require a large amount of satellite power.

Table 7-2. Binit Allocation of WSO to CCS TDA Time Slots

Function	Number of Binit
Preamble	
Guard Time	1
Carrier Recovery (PSK)	32
Binit Timing Recovery (PSK)	32
Unique Word	20
	85
Information Contents of Requests	
Broadcast Channel	
Address	16
Priority	5
Time Duration	3
DCP Interrogation	31
Voice Coordination Channel	36
Spotter Alert Channel	
Address	17
Time Duration	3
	111
Additional for Coding (143, 111) $t=4$	<u>32</u>
Total per Time Slot	228

Table 7-3. Binit Allocation of CCS to WSO TDA Time Slots

Function	Number of Binit
Preamble	
Guard Time	1
Carrier Recovery (PSK)	16
Binit Time Recovery (PSK)	16
Unique Word	20
	53
Information Content	
Broadcast	
Acknowledgement	1
Message	6
Channel Assignment	4
Time Duration	3
DCP Acknowledgement	3
Voice Coordination	
Acknowledgement	1
Message	6
Channel Assignment	16
Time Duration	3
Spotter Alert	
Acknowledgement	1
Message	6
Channel Assignment	4
Time Duration	3
Spotter Report	
Notification	1
Channel Assignment	6
Time Duration	3
	67
Additional for Coding (95, 67) $t=4$	<u>28</u>
Total per Time Slot	148

7.7 BASELINE SATELLITE SYSTEM

This paragraph discusses a baseline satellite DWS synthesized on the basis of the system requirements (Section 5) and technical considerations just presented. The baseline system essentially satisfies all system requirements and is later used to derive alternative satellite systems (Paragraph 7.8). Figure 7-10 depicts the system concept and shows the approximate frequencies* employed in the baseline system. The system is a two-satellite system, although only one is shown in the figure. One satellite is located at 110° W longitude and the other at 130° W longitude. Half the load is carried by each satellite except during eclipses when a single satellite covers the entire area at half the normal system capacity. A description of the operation of the system is given first, followed by descriptions of the transponder, the ground terminals, and the power budget.

An artist's conception of the satellite is shown in Figure 7-11. The large (8.6 meter diameter) antenna provides five beams for transmitting warnings to the public at 790 MHz; the two panels at the bottom are the solar arrays. Three additional antennas for the other functions are shown. Their sizes and operating frequencies are (from left to right) 0.86 meter and 2 GHz, 2.18 meters and 400-790 MHz, and 0.29 meter and 6 GHz.

7.7.1 Baseline System Operation

The operation of the baseline system is described in terms of its four basic functions--disaster warning voice broadcasting, spotter reporting, data collection, and coordination within the system. Other communications of a control nature aid in the accomplishment of these functions.

One of the WSFOs or national centers may serve as a central control station (CCS) and provide accounting and control for the entire system. From a coverage viewpoint, a good location for the CCS would probably be in western CONUS; e.g., Boulder, Colorado. The CCS receives information and requests from all the WSOs on a single frequency; i.e., time division access (TDA) is used. Each WSO, in turn, transmits its requests to the CCS on this channel which is called TDA channel one. On a separate frequency the CCS transmits its response on a time division basis to each of the WSOs. This channel is called TDA channel two. The CCS also performs the functions of demuting broadcast receivers for the broadcasting WSOs. The interrogation of data collection platforms (DCPs) is also performed by the CCS even though the WSOs receive the data directly from the DCPs via the satellite. Additionally, the CCS receives the spotter requests for channels to report to their respective WSO.

*Throughout the remainder of this section no distinction is made between 1.7 GHz and 2.03 GHz; they are treated as 2 GHz.

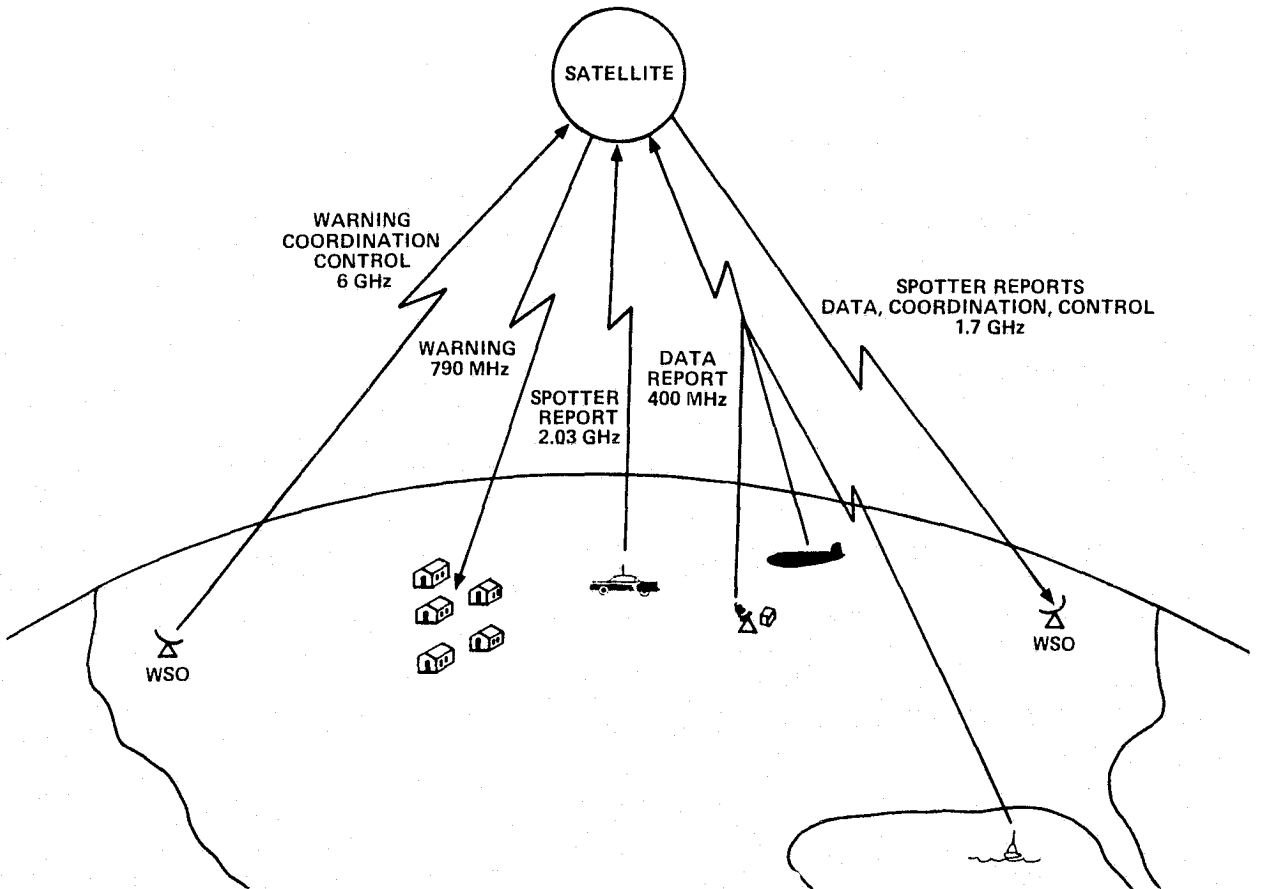


Figure 7-10. Satellite System Concept

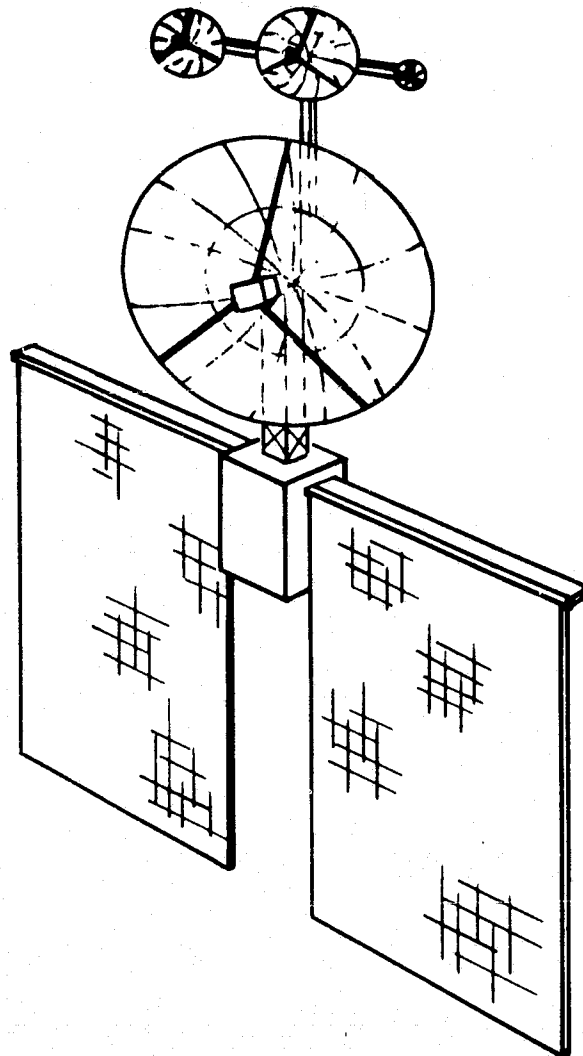


Figure 7-11. Artist's Conception of a Satellite
Baseline System

7.7.1.1 Voice Broadcasting

A WSO desiring to broadcast any warning first makes a request via TDA channel one for a broadcast channel. The CCS, upon receipt of this request, assigns a channel. The CCS then demutes the broadcast receivers, tunes them remotely to the proper channel, and notifies the WSO of the channel assignments via TDA channel two. The system is then ready for the WSO to begin broadcasting. If a broadcast channel is not available, the CCS queues the request and notifies the WSO. At the end of the broadcast, the WSO immediately notifies the CCS, via the TDA link, of the availability of that broadcast channel. The CCS confirms the message, and the broadcasting events are completed for that WSO. The WSO uses a precedence level in requesting a broadcast channel. This level depends on the importance and urgency of the broadcast and determines its position in the service queue.

7.7.1.2 Spotter Reporting

When a spotter in the field requires a channel to transmit information to the local WSO, he presses a button on his receiver-transmitter unit to transmit digitally on a random access basis a channel request to the CCS. The CCS then automatically sends the spotter and his WSO the channel assignment which the spotter uses to report by FM voice to the WSO. The channel on both the spotter and WSO communication equipment are automatically tuned to the proper one of 50 channels by a communications link from the CCS.

7.7.1.3 Data Collection

The data collection in this system operates with self-timed and interrogated DCPs just as in the present GOES system. The CCS is used to interrogate the DCPs rather than the command and data acquisition (CDA) facility at Wallops Station Virginia, presently used with GOES. The CCS interrogates DCPs at the request of the WSOs, but the WSOs receive the data directly from the DCPs via satellite. The hurricane reconnaissance aircraft use DCP radio sets which are essentially of the interrogation type. The aircraft is interrogated as frequently as determined necessary by NHC in Miami.

7.7.1.4 Voice Coordination

When a WSO desires to communicate with other WSOs he requests to do so via TDA channel one. The CCS, via TDA channel two, tells each of the WSOs involved which of the allocated frequencies to transmit on and which to receive on. A single WSO wishing to communicate with another transmits on one frequency and receives on another.

As an example of conference usage, consider a single WSO wishing to communicate with three other WSOs in a conference. It transmits on one frequency and receives on

three others simultaneously. All four WSOs transmit on separate frequencies while simultaneously receiving on these downlink frequencies. A fourth downlink frequency, of course, corresponds to a station's own message, and it could be tuned in too, if desired.

7.7.2 Baseline Satellite Transponder Configuration

7.7.2.1 General

A baseline satellite transponder configuration for the DWS is shown in Figure 7-12. All four antennas, with the exception of antenna b for voice broadcasting to the public, have northern hemisphere coverage. Antenna b is a multibeam broadcasting antenna operating at approximately 790 MHz. The five beams on antenna b illuminate (see Figure 7-3) the 50 states and the Caribbean area to provide relatively high gain spot beams which reduces the required satellite transmitter power. Figure 7-12 shows the high-level amplifications, mixing, demultiplexing, and high-power multiplexing. None of the low-level amplifications are shown. All 6-GHz signals are mixed down to an intermediate frequency low enough for demultiplexing them. By demultiplexing at IF, the signals may be spaced closer than if demultiplexing took place at the uplink or downlink frequencies. Therefore, a smaller overall bandwidth is required with double-conversion instead of a single-conversion repeater.

7.7.2.2 High Power Broadcasting

The satellite receives the 6-GHz broadcasting signals from the WSOs via antenna a, which has northern hemisphere coverage (NHC). NHC corresponds to a half-power beamwidth of 11.6 degrees. The signals are translated down to an IF at which they are demultiplexed into 16 channels (marked A in Figure 7-12) of which a maximum of five channels are simultaneously active. After demultiplexing is accomplished, the signals are translated up to 790 MHz broadcasting band for the high level amplification and multiplexed into five separate feeds for downlink transmission. Figure 7-13 illustrates a downlink frequency plan which satisfies the multiplexing requirements. The composite set of 16 broadcasting channel intermediate frequencies is separated at the IF but multiplexing at high power is performed for more widely separate frequencies. For example, multiplexers 1 and 2 combine frequencies that are separated by a ratio of four times the minimum frequency separation of the composite signals. The total broadcasting bandwidth is constrained by the minimum separation for successful high-power multiplexing, and the total RF bandwidth is approximately 4.25 times the minimum acceptable separation of signals for high-power multiplexing. For example, a minimum separation of 4 MHz would imply that approximately 17 MHz would be required for the broadcast band.

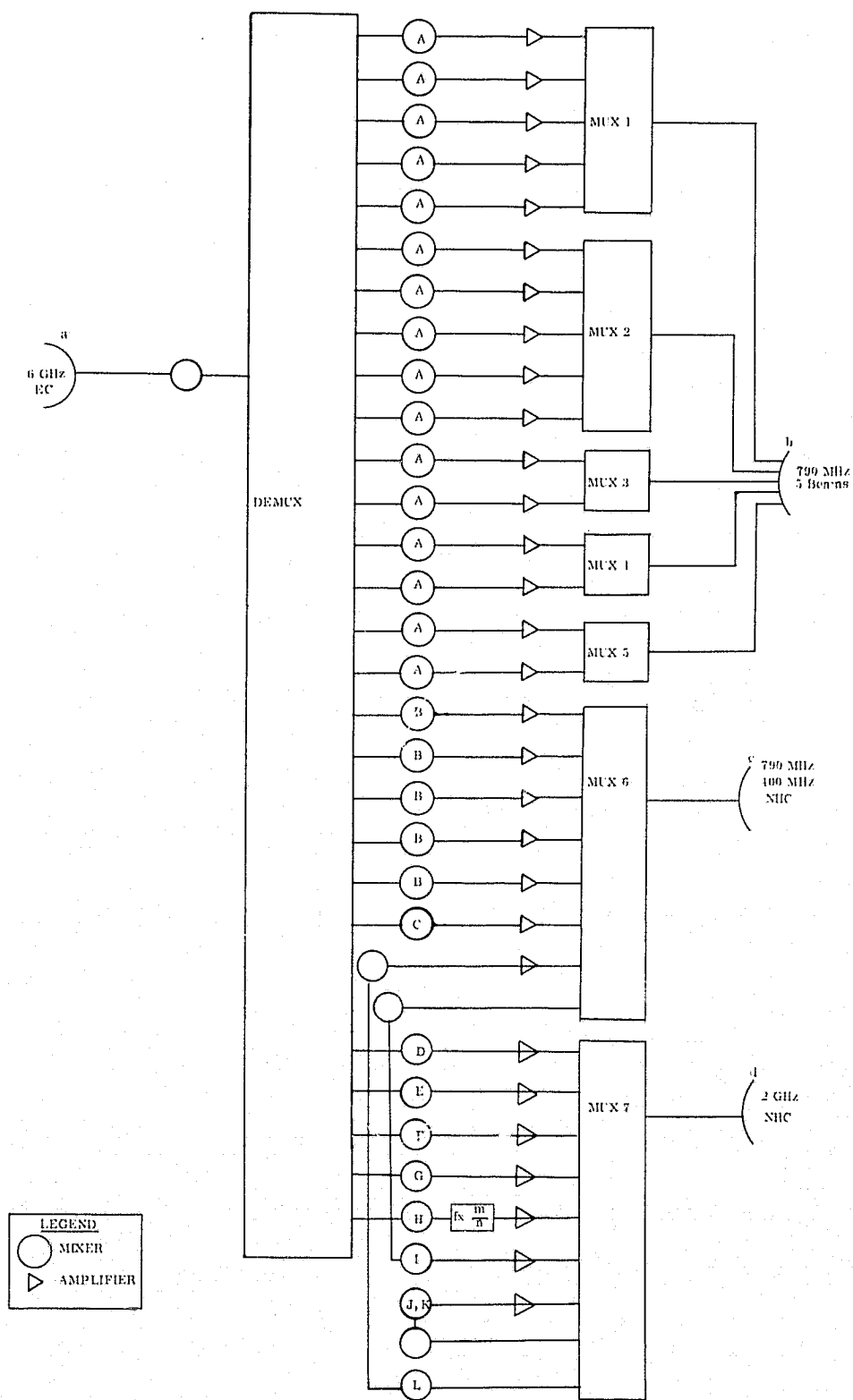


Figure 7-12. Baseline Satellite Transponder Configuration

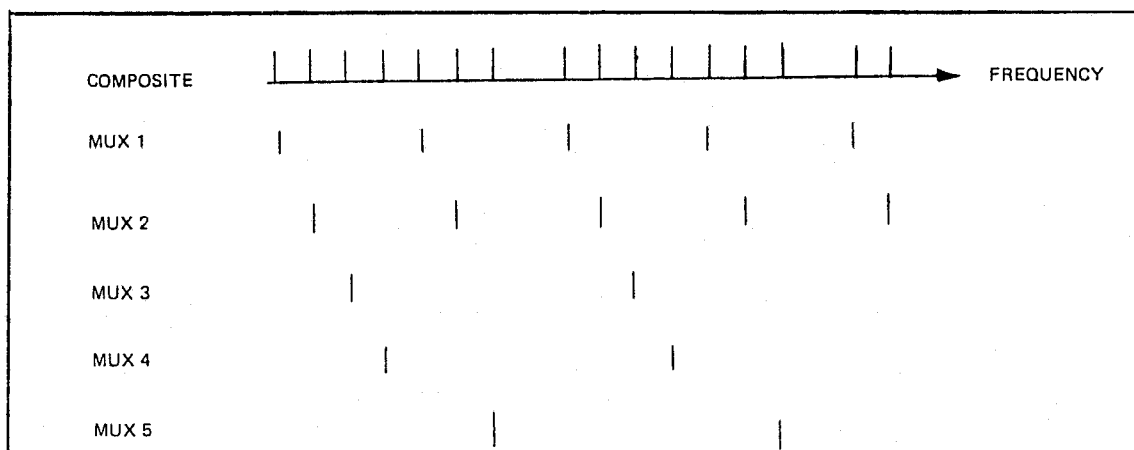


Figure 7-13. Broadcast Frequency Plan

7.7.2.3 Low Power Broadcasting

Each satellite has five FM voice lower power broadcasting channels* marked with a B in Figure 7-12. The uplink from the WSOs is in the 6-GHz band. In the satellite, these signals are treated the same as the high power broadcast signals except that the transmitter power is lower and downlink antenna c has a single NHC beam to cover all users simultaneously. These signals are all multiplexed to the one antenna feed by multiplexer 6.

7.7.2.4 Demuting for Broadcasting

A single channel is used for demuting all broadcast receivers. This is the C in Figure 7-12. The uplink channel from the CSS to the satellite is in the 6-GHz band and is received by antenna a, downconverted, demultiplexed, upconverted, and amplified. There it is multiplexed by multiplexer 6 along with the lower power broadcast channels, which are then fed to antenna c for retransmission to the earth in the NHC beam.

7.7.2.5 Time Division Access Channels

Two TDA channels, marked D and E in Figure 7-12 and used for system control, are transmitted uplink to the satellite in the 6-GHz band. They are received by antenna a, downconverted to an IF, demultiplexed, upconverted, amplified, multiplexed in multiplexer 7, and fed to antenna d for retransmission to the earth in the 2-GHz band. Channel D is transmitted from the WSOs to the CCS, while channel E is transmitted from the CCS to the WSOs.

*These channels service the spotter alert, mass media, and public officials that will use external antennas and thus avoid the building attenuation.

7.7.2.6 Spotter Control

The spotter control channel, marked F in Figure 7-12, is used by the CCS to tune the spotter transmitter after the spotter requests a channel for voice reporting. This channel, received in the 6-GHz band from the CCS, is downconverted, demultiplexed, upconverted to the 2-GHz band, amplified, and multiplexed by multiplexer 7 for retransmission to spotters via antenna d.

7.7.2.7 Voice Coordination

Ten simplex voice coordination channels are used for whatever voice coordination may be required among the WSOs and the CCS. Two simplex channels make up a duplex channel. Each of the 10 uplink frequencies in the 6-GHz band is downconverted, demultiplexed to channel G, upconverted, amplified in a common linear amplifier, multiplexed with other types of signals in multiplexer 7, and fed to antenna d for retransmission to the earth.

7.7.2.8 Pilot Signal

To maintain the proper downlink broadcasting frequencies, a pilot signal transmitted by the CCS to the WSOs can be used to detect the frequency drift resulting from local oscillator drift in the satellite. The WSOs can compensate for the satellite oscillator drift by changing the uplink frequency. Channel H is shown in Figure 7-12 for this purpose. The pilot signal is received in the 6-GHz band by antenna a. The signal is then downconverted, demultiplexed, and upconverted. The resulting signal can be multiplied by a known rational number before final amplification, multiplexed with other signals and transmitted to the WSOs via antenna d.

7.7.2.9 Data Collection

Data collection from the DCPs is performed similarly to that on the GOES system except that the data is received by the WSOs in addition to a central station. The uplink channels from the DCPs are received via a broad beam at antenna c. They pass through a demultiplexer to channel I of the satellite. The signals are all amplified together in a single amplifier before being combined in multiplexer 7 with other signals for retransmission to the earth via antenna d. Double conversion is used to provide an IF low enough to filter out wideband noise before retransmission to the WSOs.

7.7.2.10 Spotter Reports

Spotter reports are FM voice reports from spotters in the field to the WSOs. These reports in the 2-GHz band are closely spaced in frequency and take very little bandwidth. Therefore, double conversion is used to facilitate noise filtering.

These signals are received in the 2-GHz band by antenna d. The signals are demultiplexed for passage through channel J of the satellite with the channel K signals. All these signals are linearly amplified, multiplexed with other types of signals, and retransmitted to the WSOs via the same NHC antenna that received them.

7.7.2.11 Spotter Channel Requests

All spotter channel requests are FSK signals received on a single frequency from spotters in the field on a random access basis. This is channel K in Figure 7-12 and is treated identically with channel J.

7.7.2.12 DCP Interrogation

The DCP interrogation channel is channel L in Figure 7-12. The signal is received from the CCS via antenna d. It is demultiplexed in multiplexer 7. This narrowband signal passes through a double-conversion repeater and, after amplification, passes through multiplexer 6. Finally, the interrogation signal is directed to earth via antenna c, which has approximately an earth coverage pattern (19.5 degree half-power beam-width) at the downlink frequency of 468 MHz.

7.7.2.13 Channel Summary

The communication links are summarized in Table 7-4. Each link is listed with its origin, destination, uplink and downlink frequencies, and functions. These letter designations will be used throughout the remainder of this section.

7.7.3 Ground Terminals for the Baseline System

The ground terminals for the baseline satellite system include the broadcast receiver, WSO, CCS, spotter, and DCP and are presented separately.

7.7.3.1 Broadcast Receivers

The FM broadcast receivers are of the same design whether they are for high power or low power broadcasts. The spotter alert receiver is also of the same type. This receiver is demuted by a signal in the same frequency band as the warning message; i. e., in the vicinity of 790 MHz. The demuting signal is PSK while the warning signal is FM voice. Figure 7-14 shows a block diagram of the RF portion of a broadcast receiver.

A circularly-polarized conical helix is used to pick up the RF signals. These signals are amplified in a transistor amplifier having a noise figure of approximately 8 dB. This noise figure is readily achieved at low cost and does not overly degrade

Table 7-4. Summary of DWS Satellite Links

	Origin	Uplink Frequency (GHz)	Downlink Frequency (GHz)	Destination	Function
A	WSO	6.0	0.79	General Public	Voice Broadcasts
B	WSO	6.0	0.79	Mass Media, Spotters, etc.	Voice Broadcasts
C	CCS	6.0	0.79	All Broadcast Receivers	Demute and Channel Selection
D	WSO	6.0	2.0	CCS	System Control (TDA 1)
E	CCS	6.0	2.0	WSO	System Control (TDA 2)
F	CCS	6.0	2.0	Spotter	Spotter Control (Turn on and Channel Selection)
G	WSO (CCS)	6.0	2.0	WSO (CCS)	Voice Coordination
H	CCS	6.0	2.0	WSO Spotters	Pilot Tone for System Frequency Synchronization
I	DCP	0.4	2.0	WSO	Data Collection
J	Spotters	2.0	2.0	WSO	Spotter Voice Reports
K	Spotters	2.0	2.0	CCS	Spotter Channel Requests
L	CCS	2.0	0.468	DCP	DCP Interrogation

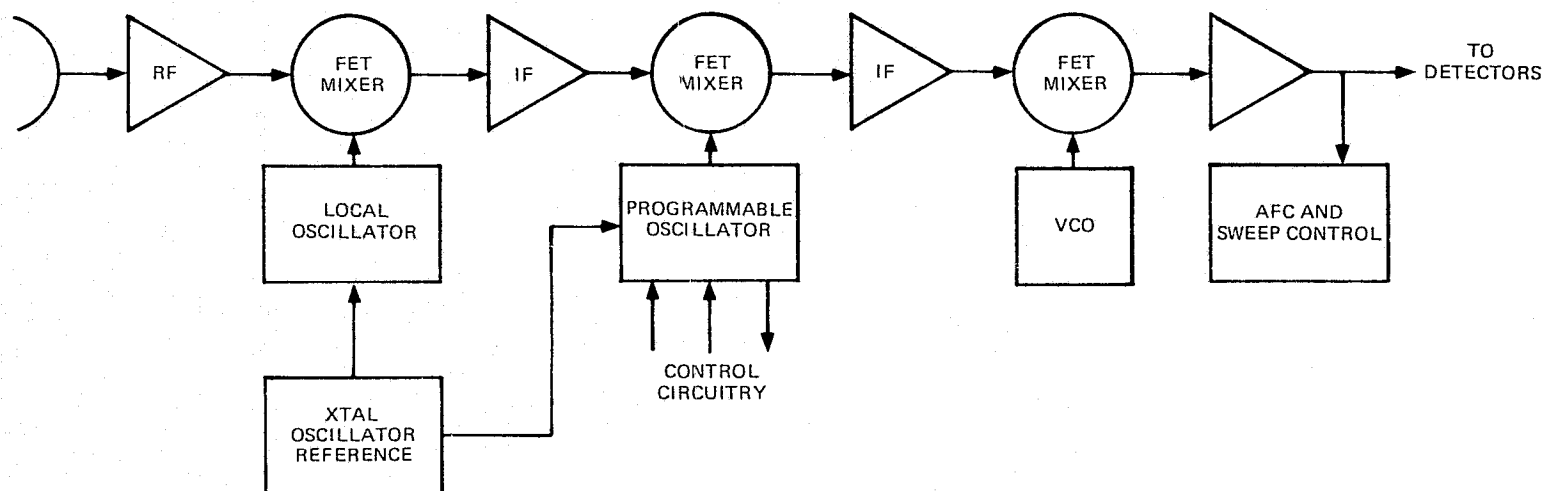


Figure 7-14. Baseline Broadcast Receiver, Simplified Block Diagram

the system, since the antenna noise temperature is rather high in many areas. Three stages of mixing and amplifying follow the RF amplifier before detection takes place. Each successive IF is lower and each IF bandwidth is smaller to provide image rejection, thereby reducing noise.

The first LO frequency is a fixed value derived from a crystal reference oscillator. The second LO frequency is derived from the same reference oscillator, but is programmable. The frequency of this second LO is specified by the PSK demuting signal, since its frequency defines the broadcast channel. An automatic frequency sweep with disable circuitry is provided to overcome the long term drift in the crystal reference-frequency oscillator.

There are three detectors used in the broadcast receiver and all use LSI phase locked loops. The first detector demodulates the FM voice, the second demodulates the PSK command signal, and the third locks on to the received carrier for tracking the demuting and channel command signal.

7.7.3.2 Baseline WSO Terminal

The baseline WSO terminal initiates and transmits disaster warnings to the general public and to public officials and news media, transmits on a TDA basis to the CCS, and transmits voice coordination messages. In addition to transmitting, the WSO receives both* TDA channels, voice coordination channels, data collection channels, and the voice spotter reports. Figure 7-15 shows a simplified block diagram of the baseline WSO terminal.

Two 1.5 meter antennas are used; one pointed at each of the two satellites. Each transmitter can be switched separately to the appropriate uplink antenna. The antennas can be pointed manually for any desired changes in direction, but tracking of the satellite is not required because of the assumed satellite stationkeeping.

In Figure 7-15 the circles represent a mixing process, the triangles are amplifiers, and the letters are the channel designators. Both the high- and low-power broadcast channels are amplified together in a linear amplifier for transmission to the particular satellite chosen by the switch ahead of the multiplexers. Channels D and G are amplified separately, and may be transmitted upward to different satellites or to the same satellite depending on the situation.

On receiving, all the incoming signals from both satellites are amplified with a separate wideband receiver for each antenna. The channels are separated and demodulated. DCP signals which are amplified by both satellites can be compared and the best of the two can be used. The Pilot signal (link H) from the CCS can be used to directly control the WSO broadcast frequencies.

*TDA 1 link from the WSOs to the CCS is used to maintain system synchronization and for general monitoring.

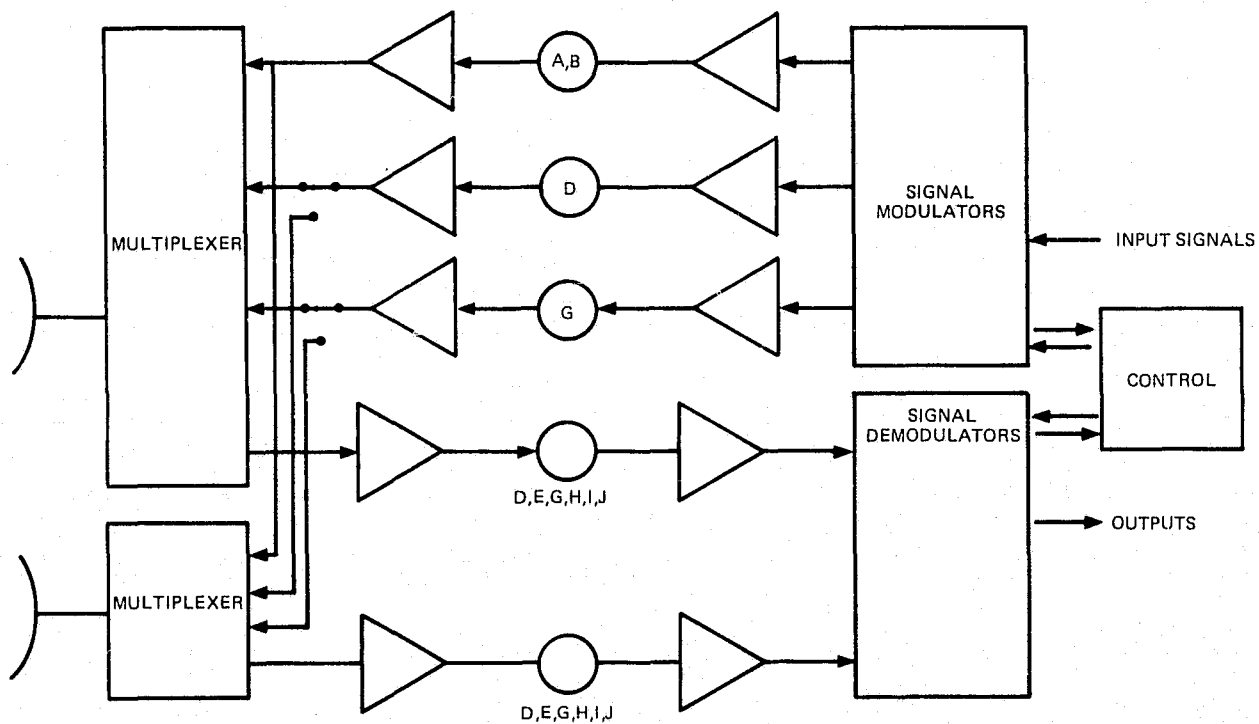


Figure 7-15. Baseline WSO Terminal, Simplified Block Diagram

C-2

7.7.3.3 Baseline CCS Terminal

The baseline CCS terminal exercises administrative control over the entire DWS. A simplified block diagram of the CCS is shown in Figure 7-16. The CCS has two identical receiving and transmitting systems connected via an interface to allow one system to operate while the other is on standby. This redundancy is required because operation of the entire DWS depends on operation of the CCS. Two separate 6-meter parabolic reflectors are used with one reflector normally aimed at each satellite.

The antennas can be interchanged by switching so that either satellite can be used with either side of the dual system. A multiplexer-demultiplexer is used with each antenna to combine the transmission signals and to separate received signals. The communication links are designated on the figure by letters in accordance with the link designators in Table 7-4.

7.7.3.4 Baseline Spotter Terminal

In addition to the broadcast type of receiver, the spotter must have a terminal at his observation point. Figure 7-17 is a simplified block diagram of the baseline spotter terminal, which can transmit, via satellite, an FSK channel request to the CCS or an FM voice signal to the local WSO. The transmit channel is one of 50 which the CCS sets via a PSK signal which is addressed to the particular spotters. The channel-setting signal is a continuous signal which can be used as a frequency standard for the spotter's transmitted frequency. When the channel selection is completed, a light appears on the spotter's terminal to indicate that the terminal is ready for voice transmission to the local WSO. The terminal is then ready to transmit a voice message to the local WSO.

The antenna must be pointed at the proper satellite even before a channel request is made. The antenna diameter is 0.4 meter so that the half-power beamwidth is 24.9 degrees at 2 GHz.

Included in the spotter terminal is a broadcast type of receiver which shares the same antenna as the other functions. When two-way voice is required between the spotter and the WSO, the 790-MHz receiver can be used on a low-power 790-MHz channel to receive WSO communications. Otherwise, a simplex FM voice reporting channel is the only link between the spotter and the local WSO.

7.7.3.5 Data Collection Platform Radio Sets

The DCPRSs for the baseline system are identical to those designed for use with GOES except that up to 400 channels may be used in the baseline system while only 150 are used with GOES (33 additional channels are provided for international use). Two types of DCPRS are used on the ground. One is self-timed and the other is interrogated. Both

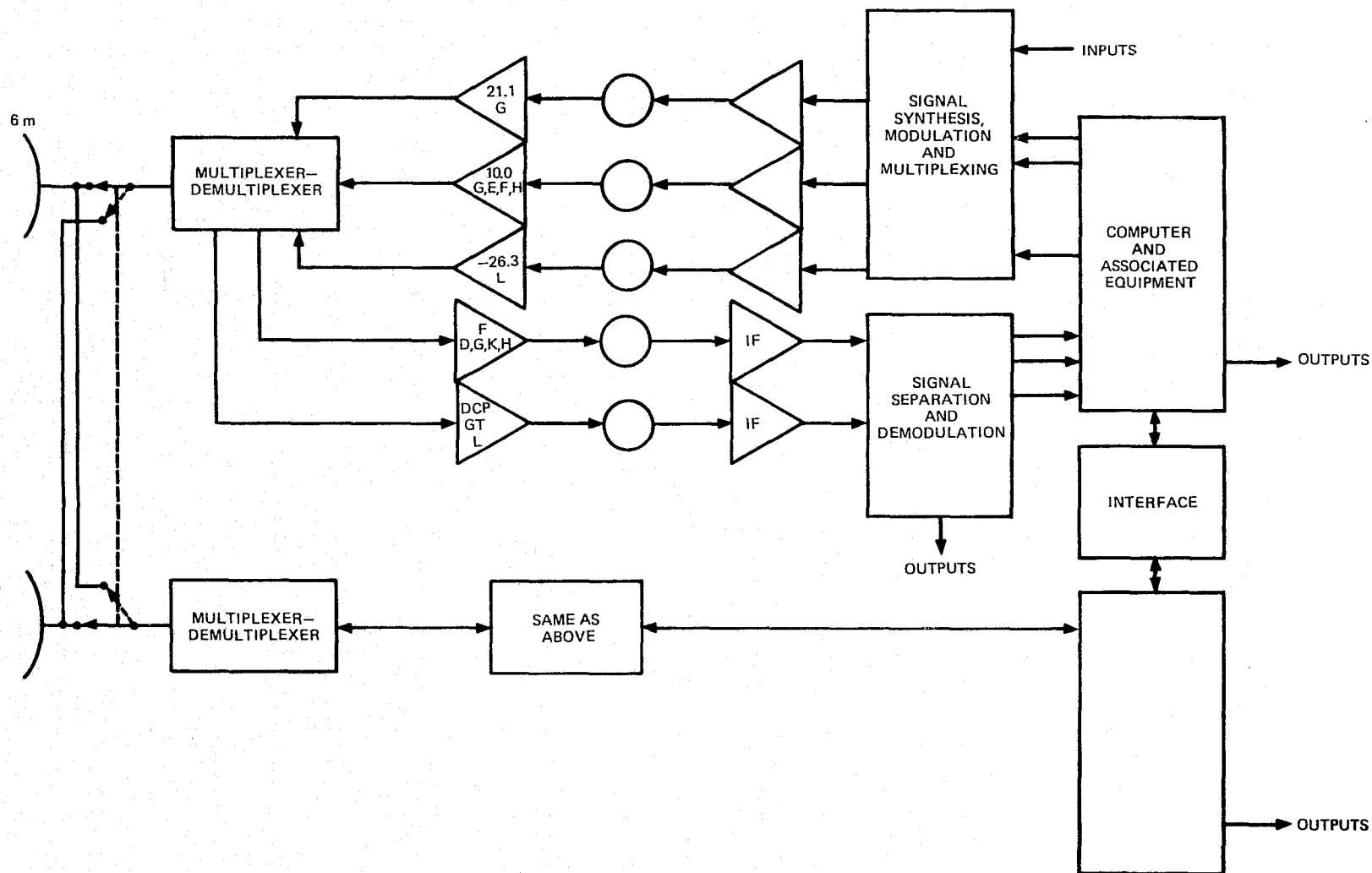


Figure 7-16. Baseline CCS, Simplified Block Diagram

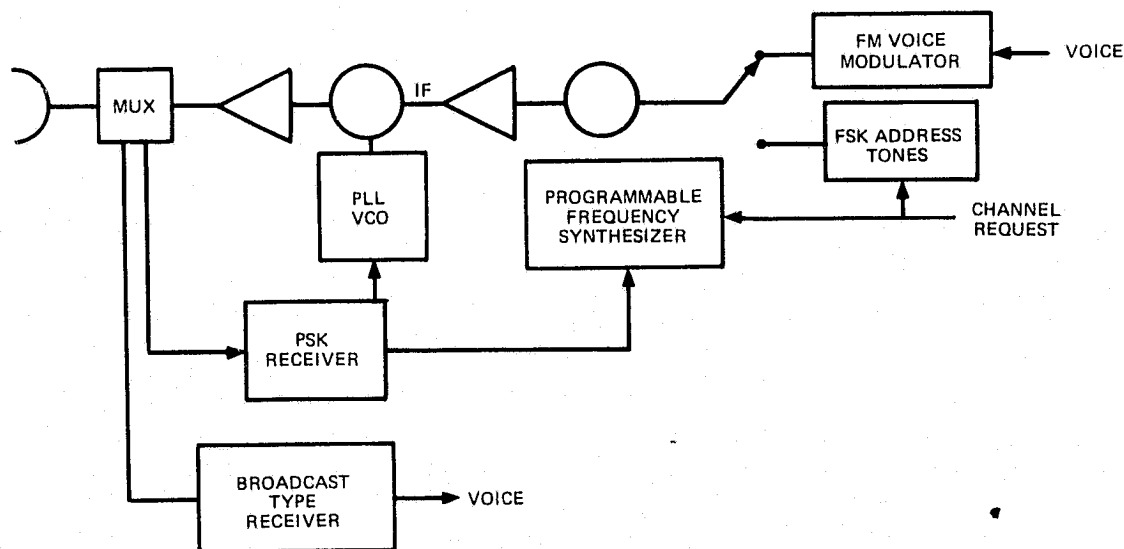


Figure 7-17. Baseline Spotter Terminal, Simplified Block Diagram

employ a helical antenna with a beamwidth of approximately 40 degrees. The self-timed unit transmits data to the local WSO via satellite on a pre-set schedule kept by an internal clock. The interrogated DCPRS transmits data only when interrogated by a 468.825 MHz signal from the satellite. The same antenna is used with a diplexer for simultaneous transmission and reception. The reply of the interrogated DCPRS is coherent with the interrogation signal which is used as a frequency reference. The output power is 5 watts for the ground units. Other units used on aircraft or on rolling buoys will require a higher level of transmitter power to compensate for a lower antenna gain. Other similar applications may also require higher power, but at the transmission frequency of 400 MHz this does not pose a problem for solid-state amplification.

7.7.4 Power Budgets for the Baseline Satellite DWS

This paragraph presents the power budgets for the baseline satellite DWS. The links are identified by their letter designators summarized in Table 7-4.

The basic characteristics of the antennas used in the baseline satellite DWS are shown in Table 7-5. Unless otherwise specified, all antennas are parabolic. None of the antennas track the satellites. At each WSO and the CCS, two antennas are used, one for each satellite. Except for the large multiple beam antenna, all satellite antennas are designed for northern hemisphere coverage or earth coverage and point near the state of Colorado. Consequently, the recommended location of the CCS is at Boulder, Colorado.

Table 7-5. Antenna Characteristics for the Baseline Satellite DWS

Location	Diameter (meters)	Frequency of Operation (GHz)	Gain (dB)	Beamwidth (3 dB) (degrees)
WSO	1.5	2.0	27.4	6.65
		6.0	42.9	2.22
CCS	6.0	2.0	39.4	1.66
		6.0	48.9	0.55
Spotter	0.4	2.0	14.8	24.9
Broadcast Receiver	0.18 x 0.18 Conical Helix	0.79	8.0	80
DCP	-	0.4, 0.468	10.0	40
Satellite	8.56	0.79	33.5	2.95
	2.18	0.79	22.5	11.6
		0.4	16.6	22.9
		0.468	18.0	19.5
	0.86	2.0	22.5	11.6
	0.29	6.0	22.5	11.6

Presented in Tables 7-6 and 7-7 are the uplink and downlink power budgets, respectively, for the baseline satellite DWS. Notes pertaining to these power budgets are contained in Table 7-8. As seen from Table 7-6, the higher power transmitters (151 watts/channel for Links A and B) are located at the WSOs. This range of transmitter power is reasonable for ground terminals such as the WSOs; however, the 18.2-dBW (66-watt) transmitter required at each spotter (link J/K) is somewhat high for a mobile transmitter, particularly since there are 100,000 spotters expected.

Because most of these transmitter powers are relatively low, most of the links have been designed to be downlink limited; i.e., the uplink contribution to the total signal-to-noise ratio is small. Also, a substantial margin (6 dB) has been included in most of the uplinks. The major exception is the voice reports from the spotters, link J. It is desirable to minimize the spotter transmitter power; however, the satellite transmitter power is relatively high, primarily because of the large number of channels required. Thus, for link J, the noise contributions are about the same for uplink and downlink.

As shown in Table 7-7, the satellite transmitter powers range from about one-tenth of a watt to 428 watts. Links A and B both use a separate transmitter for each channel. For link A, there are 16 channels with up to five simultaneously active. Thus, these broadcasting channels dominate the satellite requirements. However, links G, I, and J/K require considerable power, particularly since they all require linear operation resulting in low efficiency and peak power capabilities about 6 dB above their average RF power requirements.

7.7.5 Baseline Satellite Synthesis

7.7.5.1 Introduction

The preceding paragraphs presented some of the basic electronic parameters of the baseline satellite such as the transponder configuration, antenna sizes, receiver sensitivities, and transmitter powers. Using these parameters as inputs to models (modified and/or extended as required) contained in a computer program, a baseline satellite was synthesized in terms of such basic parameters as weight, physical dimensions, and prime power requirements. Since most of the models used are documented in Reference 9, only the more critical satellite subsystems and parameters will be addressed in the following paragraphs. Since the baseline satellite is primarily dependent upon its transponder subsystem, the transponder is presented, in Paragraph 7.7.5.2, in greater detail than other subsystems. Some of the other more dominant subsystems, such as the antennas, power, and thermal control, are discussed in Paragraph 7.7.5.3.

Table 7-6. Uplink Power Budget for Baseline Satellite DWS

		A	B	C	D	E	F	G	H	I	J	K	L
Frequency	GHz	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	0.4	2.0	2.0	2.0
Xmtr Pwr	dBW	21.7	21.7	-6.9	15.7	4.4	-9.5	21.1	-4.5	7.0	18.2	18.2	-26.3
Line, Feed, Mux Losses	dB	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	1.0	1.0	1.0
Antenna Gain	dB	36.9	36.9	48.9	36.9	48.9	48.9	36.9	48.9	10.0	14.8	14.8	39.4
EIRP	dBW	57.6	57.6	41.0	51.6	52.3	38.4	57.0	43.4	16.5	32.0	32.0	12.1
Off-Axis Loss	dB	0.6	0.6	0.8	0.6	0.8	0.8	0.6	0.8	1.0	1.0	1.0	0.7
Free Space Loss	dB	200.2 ¹	200.2 ¹	199.5 ²	200.2 ¹	199.5 ²	199.5 ²	200.2 ¹	199.5 ²	176.7 ¹	190.6 ¹	190.6 ¹	189.9 ²
Polarization Loss	dB	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.2	1.0	1.0	1.0
Margins													
Rain	dB	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	0.0	0.1	0.1	0.1
Scintillation	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	0.0	0.5	0.5	0.5
Miscellaneous	dB	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	3.0	3.0	6.0
Satellite Antenna Gain	dB	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	16.6	22.5	22.5	22.5
Off-Axis Loss	dB	4.3	4.3	0.0 ³	4.3	0.0 ³	0.0 ³	4.3	0.0 ³	4.3	4.3	4.3	0.0 ³
Received Carrier Pwr	dBW	-139.0	-139.0	-150.8	-145.0	-139.5	-153.4	-139.6	-148.4	-155.1	-146.0	-146.0	-163.6
Satellite Noise Temp ⁴	dB ⁰ K	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	28.6	28.6	28.6	28.6
Noise Pwr Density	dBW/Hz	-198.0	-198.0	-198.0	-198.0	-198.0	-198.0	-198.0	-198.0	-200.0	-200.0	-200.0	-200.0
Signal Bandwidth (Rate)	dB-Hz	42.0	42.0	20.0	38.0	36.5	20.0	43.0	30.0	20.4	43.0	33.3	20.4
Noise Suppression ⁵	dB	2.7	2.7	-	-	-	-	-	-	-	-	-	-
S/N (E/N ₀)	dB	19.7	19.7	27.2	15.0	22.0	24.6	15.4	19.6	24.5	11.0	20.7	16.0

Footnotes contained in Table 7-8.

Table 7-7. Downlink Power Budget for Baseline Satellite DWS

		A	B	C	D	E	F	G	H	I	J	K	L
Frequency	GHz	.79	.79	.79	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	0.468
Xmtr Pwr	dBW	26.3	24.0	21.5	-10.2	2.5	4.2	13.1	11.2	13.3	22.2	22.2	3.4
Line, Feed, Mux Losses	dB	1.2	1.8	1.8	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	1.0
Power Sharing Loss ⁶	dB	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	26.0	17.1	17.1	0.0
Antenna Gain	dB	33.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	18.0
EIRP	dBW	58.6	44.7	42.2	10.1	22.8	24.5	23.4	31.5	7.6	25.4	25.4	20.4
Off-Axis Loss	dB	6.2 ⁷	4.3	0.0 ³	4.3	4.3	4.3	4.3	4.3	4.3	4.3	0.0 ³	4.3
Free Space Loss	dB	182.3 ¹	182.3 ¹	182.3 ¹	189.9 ²	190.6 ¹	190.6 ¹	190.6 ¹	190.6 ¹	190.6 ¹	190.6 ¹	189.9 ²	178.0 ¹
Polarization Loss	dB	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.2
Margins													
Rain	dB	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
Scintillation	dB	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0
Miscellaneous	dB	15.0 ⁸	3.0	18.0 ⁸	6.0	6.0	6.0	3.0	6.0	6.0	3.0	3.0	6.0
Gnd Antenna Gain	dB	8.0	8.0	8.0	39.4	27.4	14.8	27.4	14.8	27.4	27.4	39.4	10.0
Off-Axis Loss	dB	3.0	3.0	3.0	0.5	0.3	1.0	0.3	3.0	0.3	0.3	0.5	1.0
Received Carrier Pwr	dBW	-140.9	-140.9	-158.4	-148.5	-152.6	-164.2	-149.0	-159.2	-167.8	-147.0	-130.2	-159.1
Terminal Noise Temp	dB-°K	36.3 ⁹	36.3 ⁹	36.3 ⁹	27.1	27.1	28.9	27.1	28.9	27.1	27.1	27.1	33.1
Noise Pwr Density	dBW/Hz	-192.3	-192.3	-192.3	-201.5	-201.5	-199.7	-201.5	-199.7	-201.5	-201.5	-201.5	-195.5
Signal Bandwidth(Rate)	dB-Hz	42.0	42.0	20.0	38.0	36.5	20.0	43.0	30.0	20.4	43.0	33.3	20.4
S/N ($\frac{E}{N_0}$) (downlink)	dB	9.4	9.4	13.9	15.0	12.4	15.5	9.5	10.5	13.3	11.5	38.0	16.0
Uplink Contribution	dB	0.4	0.4	0.2	3.0	0.4	0.5	1.0	0.5	0.3	3.3	17.2	3.0
Total S/N ($\frac{E}{N_0}$)	dB	9.0 ¹⁰	9.0 ¹⁰	13.7 ¹¹	12.0 ¹²	12.0 ¹²	15.0 ¹³	8.5 ¹⁴	10.0 ¹⁵	13.0 ¹⁶	8.5 ¹⁴	20.8 ¹⁷	13.0 ¹⁶

Footnotes contained in Table 7-8.

Table 7-8. Notes for Power Budgets

1. Elevation angle is 10 degrees.
2. Elevation angle at CCS is 45 degrees.
3. Satellite antennas are pointed at CCS.
4. Satellite noise temperature is based on antenna temperature of 290°K, a 1-dB line loss, and noise figures of 5 and 3 dB for preamplifiers operating at 6 and 2 GHz (also 0.4 GHz), respectively.
5. All links, except links A, B, and C, are operated upon linearly in transponder. Single carrier channels of links A, B, and C contain hard limiters. To compensate for frequency uncertainties, these channel bandwidths are 80 kHz (the detection bandwidths at receivers are 16 kHz). The signal-to-noise ratios into hard limiters in links A and B are 10 dB which provides a noise suppression factor of 2.7 dB resulting in a signal-to-noise ratio of 19.7 dB in a 16-kHz detection bandwidth. Signal power in link C is less and resulting noise suppression factor for that link is insignificant.
6. Several links contain multiple channels using the same linear transmitter. To determine required satellite transmitter power, maximum number of simultaneous signals were included. To show detection performance on a single channel, a power sharing loss factor is included to convert satellite power (EIRP) to a single channel.
7. As stated in Paragraph 7.2.2, not all CONUS areas are within 4.3 dB contours. Maximum off-axis loss is 6.25 dB located in north central CONUS.
8. Building attenuation of 15 dB is used. 3-dB margin is added to attenuation for link C.
9. Home receiver is urban noise-limited with an antenna temperature of 2714°K, derived assuming urban noise being uniformly distributed from 0° to 10° in elevation and omnidirectional in azimuthal plane. Since home receiver is external noise-limited, to minimize receiver cost, a noise figure of 8 dB is used.
10. With signal-to-noise ratio of 9 dB and index modulation of 1.5, baseband signal-to-noise ratio will exceed 16 dB.
11. Required E/N_o including a 2 dB implementation loss for a (26, 16) code (see Paragraph 7.2.5).
12. Using codes designated in Tables 7-2 and 7-3 and an $E/N_o = 12.0$ dB, message error rate is much less than 10^{-6} . However, to ensure adequate power for synchronization, an $E/N_o = 12$ dB is used.
13. With a simple coded address for the spotters, address errors can be made to be much less than 10^{-8} .
14. FM receivers at WSOs will be of better quality than home receivers.
15. Nominal signal-to-noise ratio of 10 dB is used for acquisition purposes.
16. Present required E/N_o for GOES is 13 dB.
17. Since available carrier power is determined by requirements on link J, a pulse duration must be chosen to satisfy the requirements in Appendix I. Appendix I shows that acceptable performance can be achieved with a signal-to-noise power density much less than the available 71.3 dB-Hz.

7.7.5.2 Transponder Subsystem

For a multichannel high power transponder, the dominant parameters of weight and power result primarily from the transmitters. Thus, most of the following discussion will be related to the transmitters.

Figure 7-17 illustrates the model that was used to determine the transmitter weight. Weights are given for each of the broadcast frequency bands. The lighter weight solid state devices are used up to their estimated (for the 1980s) maximum power capability. The curves were taken from Reference 9 except that the solid-state maximum power capability in the 2.50 - to 2.69 GHz band was extended to 100 watts.

Using the curves in Figure 7-18, the transmitter weights found are shown in Table 7-9 for each link. Note that links D, E, and F use a common linear transmitter as do links J and K. The average operating power was obtained from the downlink power budget, Table 7-7. Several of the links require linear transmitters, thus must have a maximum power capability significantly above the required operating point; a 6 dB factor is used in Table 7-9. The number of required transmitters follows from the transponder configuration illustrated in Figure 7-12. A redundancy factor of two is used for all transmitters. The same factor is also used for the receiving and IF portions of the transponder so that two complete transponders are required. Using the model in Reference 9, a greater redundancy factor is required for the higher power transmitters. However, it is believed that the lower redundancy factor (2) can be achieved if extensive research and development programs are initiated. Furthermore, a complete reliability analysis is required to precisely determine the required redundancy for various system performances. Also, the use of two satellites providing essentially identical coverage will impact the reliability results. As can be seen from Table 7-9, the broadcasting functions (links A and B) dominate the transmitter weights, and the links from the spotters to the WSOs (J and K) also result in significant weights. The total transponder weight, including 181 kg for the other transponder functions, is 1035 kg.

Table 7-10 presents the power requirements for the transmitters for each of the links. For transmitters operating in saturation, an efficiency of 45 percent was used. For the transmitters operating in the linear region, an efficiency of 13 percent was used. A converter efficiency of 85 percent was used for all transmitters. Again, the transponder requirements are dominated by the broadcasting (links A and B) functions, with links J and K also requiring large amounts of power. Note that the requirement for linear operation results in relatively large power requirements. The total transponder power requirements, including 285 watts for the other transponder functions, is 11,475 watts.

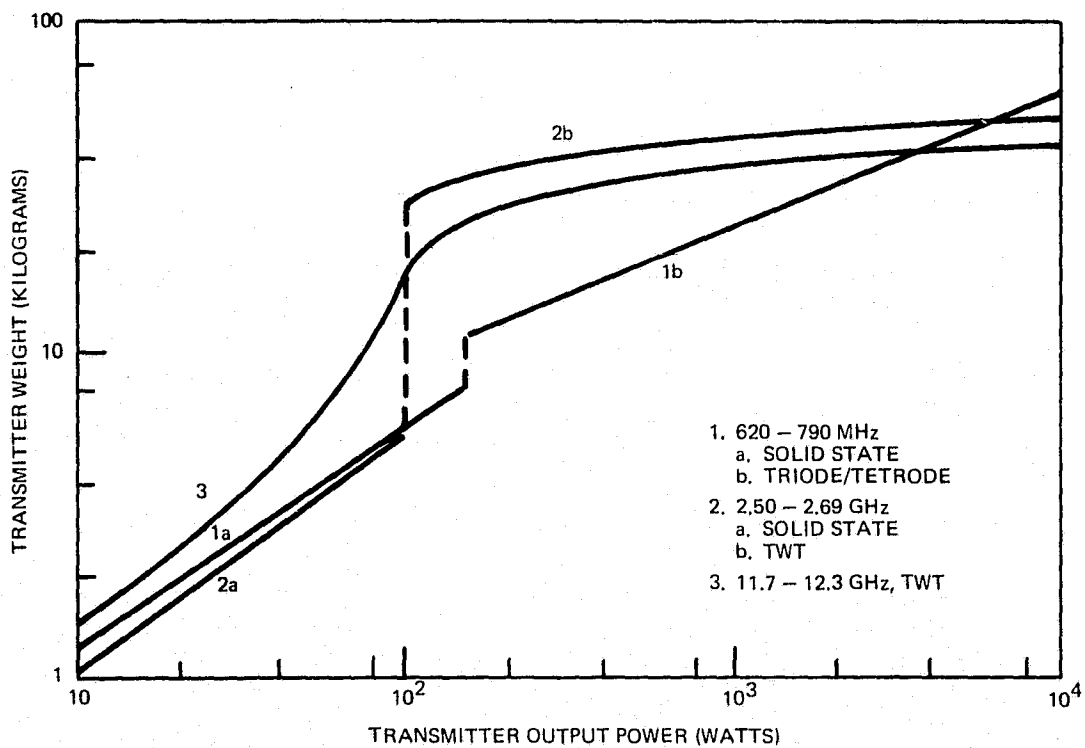


Figure 7-18. Transmitter (Power Amplifier and Supply) Weight as a Function of Maximum Output Power

Table 7-9. Baseline Transponder Weight Breakdown

Links	A	B	C	D,E,F	G	H	I	J,K	L
Average Operating Power/Transmitter (Watts)	427	251	141	4.5	20.4	13.2	21.4	166	2.2
Maximum Power/Transponder (Watts)	427	251	141	18	81.6	13.2	49.6	664	2.2
Weight/Transmitter (kg)	18.2	14.2	7.7	1.6	5.4	1.4	5.4	42.6	0.9
Number of Transmitters	16	5	1	1	1	1	1	1	1
Redundancy	2	2	2	2	2	2	2	2	2
Total Weight (kg)	582.4	142	15.4	3.2	10.8	2.8	10.8	85.2	1.8

Table 7-10. Baseline Transponder Power Requirements

Links	A	B	C	D, E, F	G	H	I	J, K	L
Power/Transmitter (Watts)	427	251	141	4.5	20.4	13.2	21.4	166	2.2
Number of Active Transmitters	5	5	1	1	1	1	1	1	1
Total Power of Transmitters (Watts)	2135	1255	141	4.5	20.4	13.2	21.4	166	2.2
Transmitter Efficiency (%)	45	45	45	13	13	45	13	13	45
Converter Efficiency (%)	85	85	85	85	85	85	85	85	85
Transmitter Prime Power (Watts)	5580	3280	370	40.6	185	34.6	19.4	1500	5.8

7.7.5.3 Other Satellite Subsystems

Since the physical sizes of the antennas are primarily a result of the coverage requirements (given an operating frequency), the remaining major factor of the antenna subsystem is its weight. The model contained in Reference 9 considers two types of parabolic antennas: rigid antennas and, for those with diameters exceeding 2.74 meters (9 feet), a space erectable antenna. Based upon actual satellite antenna data, curves were derived which related antenna diameter to weight. Separate curves were derived for the rigid and space erectable antennas. Using these curves (Reference 9), the 8.6 meter (space erectable) antenna weight is 53 kg and the entire antenna subsystem weight is 77 kg.

The prime power subsystem model calculates that subsystem's total weight, prime power, and solar array area. Some of the inputs to the model include the prime power requirements of the transponder and housekeeping functions, the satellite lifetime, and the stabilization mode. Units considered within the subsystem include inverters, regulators, shunts, power control, orientation mechanics, and wiring harnesses. The total weight of the prime power subsystem is 796 kg with the solar array weighing 352 kg, using a factor of 0.0226 kg/watt. The beginning of life (BOL) solar array power is 15,510 watts and the end of life (EOL) power is 13,350 watts after 5 years. Using a factor of 129 watts per square meter, the solar array area is 120 square meters.

For high powered satellites a considerable amount of satellite weight is used for the thermal control subsystem to dissipate heat. Most of the heat is generated by the high power transmitters and the line losses between the transmitters and antennas. The thermal control model is adopted from the ATS-F configuration consisting of the heat pipe assembly, louvres, and insulation. Two basic parameters in the model are 31.7 and 36.2 kg/kilowatt for the weight of the louvres and heatpipes, respectively, to dissipate 1 kilowatt of heat. The total weight of the thermal control subsystem is 869 kg.

Table 7-11 presents the baseline satellite subsystem weights as well as the solar array area and BOL power. The most comparable existing satellite to the baseline DWS satellite is the ATS-F which weights 1335 kg and has a BOL power of 600 watts. The baseline DWS satellite is a much more advanced satellite than existing satellites; a factor of 2.73 in weight and a factor of 25.9 in prime power over that of the ATS-F. Additionally, the baseline satellite is relatively expensive, as shown in Section 8. Because of these considerations, alternative satellite systems were synthesized and compared; the results of which are presented in Paragraph 7.8.

7.8 COMPARISON OF BASELINE AND OTHER ALTERNATIVE SATELLITE SYSTEMS

Alternative satellite systems can be derived from the baseline system by varying the parameters of the baseline satellite which will affect its reliability, weight, and capacity of the satellite. The systems that result from certain variations are compared

Table 7-11. Baseline Satellite Summary

Subsystem	Weight (kg)
Transponder	1035
Antenna	77
Power	796
Stabilization	334
Thermal Control	869
Structure	516
Miscellaneous	23
	<hr/>
TOTAL	3650
Solar Array Area (m ²)	120
BOL Power (watts)	15,510

in Table 7-12 with the baseline system and with each other. Weight breakdown by subsystem for these cases is shown in Table 7-13.

The satellites are described in terms of their redundancy. A low redundancy satellite has a redundancy factor of two and an RF transmitter output power greater than 200 watts per channel. A high redundancy satellite has either a redundancy factor of four whenever the RF transmitter output power is greater than 200 watts per channel or a redundancy factor of two whenever the RF power does not exceed 200 watts per channel. The redundancy factor is the number by which the number of transmitting amplifiers is multiplied.

7.8.1 Baseline Satellite - Cases 1 and 2

Two baseline satellites are compared in Cases 1 and 2 of Table 7-12. The first is a high redundancy satellite while the second is a low redundancy satellite. The RF transmitting power per channel (A) is 427 watts; thus, there are twice as many high power transmitters (64 compared to 32) in the high redundancy satellite as in the low redundancy one. This is reflected in the satellite weight difference of 1084 kg.

7.8.2 Case 3

Case 3 is identical to the baseline satellite of Case 1 except that outside broadcast receiving antennas are used. Attenuation was reduced by 10 dB. The high-power broadcasting transmitter is no longer required. Only 42.7 watts is necessary and the factor of ten reduction of RF power is reflected in both satellite weight and prime power. Table 7-12 shows a reduced satellite weight of 1091 kg and a reduced BOL prime power of 8585 watts.

7.8.3 Case 4

Case 4 is the same as the low-redundancy baseline case (Case 2) except that the number of simultaneous broadcasting channels is reduced from five to three with the maximum number of channels allocated to the five beams on a 3, 3, 1, 1, 1 basis as shown in Table 7-12. Three channels are available in each of the two beams covering CONUS while only one is available in each of the other three beams. The reduction in capacity is reflected in the significant reduction of satellite weight and prime power with respect to the low redundancy baseline satellite.

7.8.4 Case 5

A further reduction in the number of simultaneous broadcast channels to two further reduces the satellite weight from 2531 kg (Case 4) to 1704 kg and reduces the corresponding BOL prime power from 10,690 to 6571 watts. The allocation of channels per beam for each of the five beams is shown in Table 7-12, with a maximum of two simultaneous channels in the beam illuminating only eastern CONUS.

Table 7-12. Comparison of Alternative Satellites

Case Number	Number of Simultaneous (A) Channels/Satellite	(A) Channels/Beam	Redundancy	Broadcasting XMTR Per/Channel (W)	Antenna Dia.(m)	Satellite Weight (kg)	Solar Array Power BOL (W)
1	5	5, 5, 2, 2, 2	High	427	8.6	4,734	15,510
2	5	5, 5, 2, 2, 2	Low	427	8.6	3,650	15,510
3	5	5, 5, 2, 2, 2	High	42.7	8.6	1,991	8,585
4	3	3, 3, 1, 1, 1	Low	427	8.6	2,531	10,690
5	2	2, 1, 1, 1, 1	Low	427	8.6	1,704	6,571
6	2	2, 2, 1, 1, 1, 1, 1, 1, 1, 1	High	89	16.8	1,151	2,319
7	2	2, 1, 1, 1, 1	Low	427	8.6	1,319	4,654
8	2	2, 2, 1, 1, 1, 1, 1, 1, 1, 1	High	89	16.8	1,134	2,235
9	2	2, 1, 1, 1, 1	Low	4,677	2.6	7,187	43,167

Table 7-13. Satellite Subsystem Weights (kilograms)

Case Number	1	2	3	4	5	6	7	8	9
Subsystem									
Transponder	1887	1035	446	650	423	263	348	258	1074
Antenna	77	77	77	77	77	270	77	270	49
Power	796	796	476	574	383	183	293	179	2050
Stabilization	408	334	219	258	199	157	170	156	565
Thermal Control	869	869	488	605	378	118	245	113	2389
Structure	674	516	262	344	221	138	163	135	1036
Miscellaneous	23	23	23	23	23	22	23	23	24
TOTAL	4734	3650	1991	2531	1704	1151	1319	1134	7187

7.8.5 Case 6

Without changing the number of simultaneous broadcast channels from the two used in Case 5, the number of satellite antenna beams is increased to 12 with the allocation of channels per beam as shown in Table 7-12. Also, the spotter communications is changed from a maximum of 50 simultaneous channels to a single digital random-access channel. Each spotter can send 50 bits of information at a time to the local WSO via the satellite. Increasing the number of beams for the same coverage area as that in the baseline system reduces the beam size and increases the antenna gain. The parabolic reflector on the satellite increases from 8.6 meters for the five-beam case to 16.8 meters for the 12-beam case. With the resultant increase in satellite antenna gain, the RF power required to communicate with the broadcast receivers decreases to 89 watts per channel. Because of this reduction in RF power and the reduced spotter communication power, the BOL prime power decreases too.

Since the number of simultaneous broadcast channels is unchanged, the number of frequencies required is also unchanged. Additional amplifiers are required but affect only the satellite weight and not the array power.

7.8.6 Case 7

Case 7 is identical to Case 5 except that the spotter communications is changed from a maximum of 50 simultaneous channels to a single digital random-access channel as in Case 6. This results in a significant reduction in weight and BOL prime power even though the broadcast channels are unchanged.

7.8.7 Case 8

This case is the same as Case 6 except for the complete removal of the digital spotter communications. The 12-beam high redundancy satellite drops in weight from 1151 to 1134 kg and the BOL prime power drops from 2319 to 2235 watts. These differences in weight and power are very small. Thus, little is gained in completely removing the digital spotter reporting communications, most of the gain having already been realized in going from 50 voice channels to a single digital random access channel.

7.8.8 Case 9

This case is identical to the low redundancy baseline Case 2 except that the broadcast frequency band is at 2.6 GHz. Five beams per satellite cover the same area covered in the baseline system. Since the beams are the same size the satellite broadcast antenna decreases according to the frequency change. The 10.3-dB difference in free-space loss increases the transmitted RF power required for high-power broadcasting. The power required at 2.6 GHz is 4677 watts per channel. Along with this tremendous increase in RF power is a corresponding increase in satellite weight and BOL prime power. The satellite weight increases from 3650 to 7187 kg and the BOL prime

power increases from 15,510 to 43,167 watts, clearly an impractical configuration. Thus, the lower broadcasting frequency is the preferred one.

7.9 HYBRID SYSTEM

With a goal of minimizing satellite size (cost), a hybrid DWS was developed where the warning to the general public was done by terrestrial transmitters such as those used in the baseline terrestrial system. The inputs to the terrestrial transmitters are from the satellite at 2.0 GHz. At each terrestrial transmitter site there are two (one for each satellite) 1.5-meter parabolic receive-only antennas. Since there are no satellite transmissions at 790 MHz, the 8.6-meter parabolic antenna is not needed. This antenna is replaced by a 3.4-meter parabolic antenna so that the five-beam coverage is used at 2.0 GHz. All other functions operating in the 2.0 GHz region will also use this multiple beam antenna.

The transponder configuration for the hybrid system is shown in Figure 7-19 with the letter designators as defined in Table 7-4. The power amplifiers are illustrated as small rectangles and contain their powers in watts. To the left of the rectangles is a number in parenthesis indicating the number of simultaneous transmissions that can be sent through each transmitter. Unlike the baseline system, all transmitters can simultaneously transmit their maximum number of channels. All transmitters, except the one servicing link L, handle multiple carriers and have been sized to operate in their linear region.

Links A, B, and C are considered jointly with five channels into each power amplifier. A maximum of 15-channels (links A, B, and C) are possible in each of the Eastern and Western CONUS beams and ten channels in each of the remaining beams.

There can be up to 50 simultaneous voice channels from the spotters (link J) to WSOs in the beams for Eastern and Western CONUS and up to ten for each of the remaining beams. The spotter channel request link (K) shares the power amplifier with link J in the Western CONUS beam.

The remaining links operating in the 2.0-GHz band use a common power amplifier. The output from the power amplifier is split uniformly among the five beams.

Using the configuration shown in Figure 7-19, the transponder power requirements and weights were determined and input to the satellite model. The resulting key satellite parameters are a weight of 750 kg and solar array power of 2.4 kilowatts. This satellite is within the present state-of-the-art.

7.10 DWS SATELLITE RELIABILITY AND LAUNCH STRATEGY

This reliability analysis of the DWS postulates a satellite reliability and mean-time-to-failure (MTTF) and then examines the reliability of the total DWS satellite system

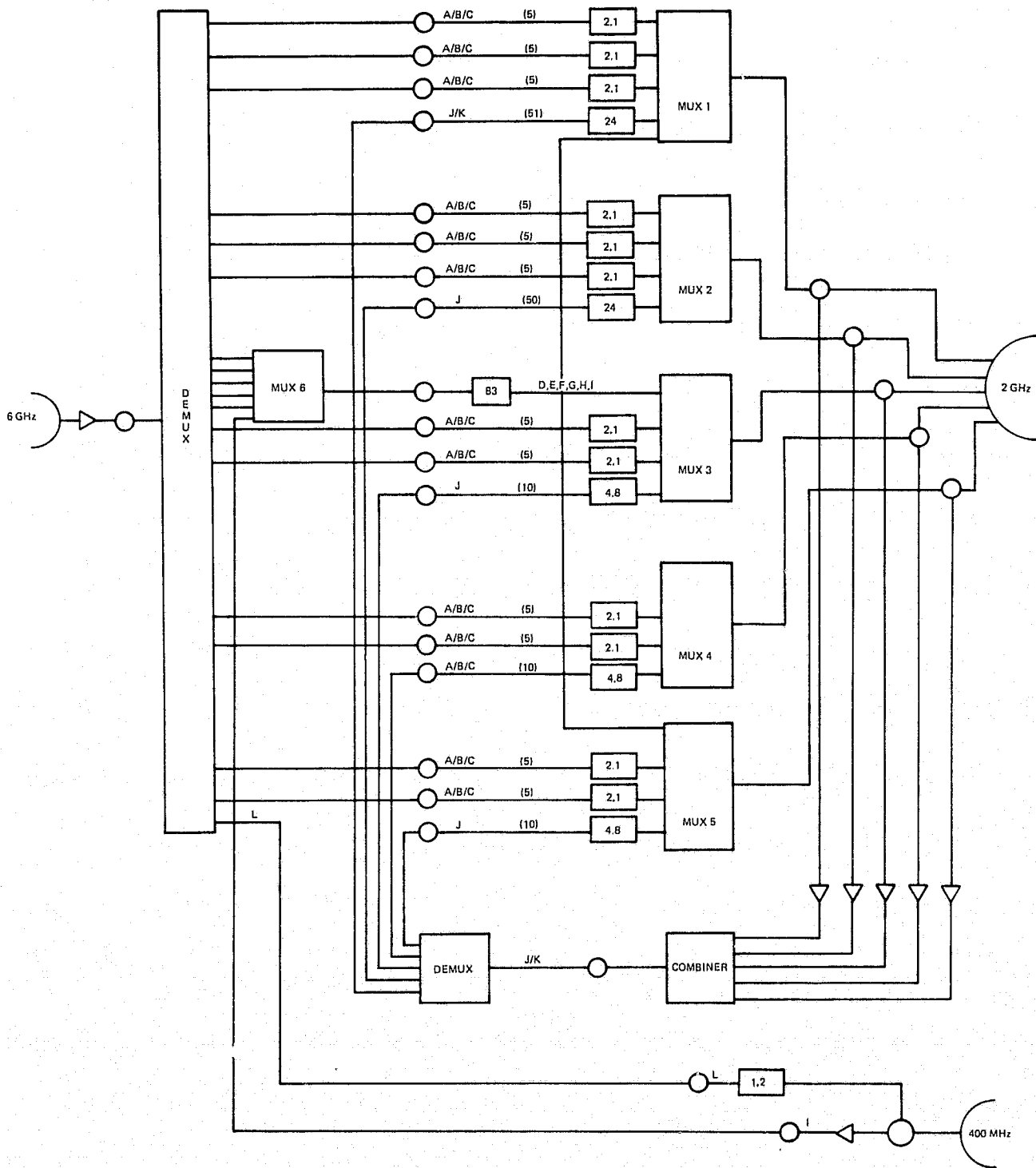


Figure 7-19. Hybred System Transponder Configuration

using the postulated values. The DWS satellite system consists of the East and West stations which are separated by at least 18 degrees so that the geostationary satellites in each station will not be in eclipse or partial eclipse at the same time. Depending on the launch strategy, there may be one or more satellites considered at each station. The design goal for the DWS satellite is an expected life of 5 years; this value has been postulated as the MTTF for this reliability analysis. Data concerning the shape of the reliability curve are not available; it is not expected that this curve will be exponential because of the extensive redundancy designed into the spacecraft. To approximate the typical S-shaped reliability curve of equipment possessing extensive redundancy, the relationship that has been used is

$$R(t) = (1 + \lambda t) \exp(-\lambda t) \quad (7-1)$$

where $R(t)$ = reliability at t years

λ = failure rate per year

This is the equation for identical components in standby redundancy and, although it is slightly optimistic, it is a good approximation based on data available at Computer Sciences Corporation for similar satellites. Using the postulated MTTF of 5 years for the DWS satellite, the value of λ is 0.4 which represents an average of one failure every 2.5 years. This reliability function is shown in Figure 7-20 for launch probability values of 1.0, 0.9, and 0.8. For comparison, the reliability curve for exponential failure is also shown in this figure.

The selection of a launch strategy for DWS depends not only on satellite reliability but also on the occurrence of solar eclipses for geostationary satellites. During the two periods each year centered on the spring and autumnal equinoxes, the geostationary DWS satellite will be in solar eclipse once each day. Each of the periods is about 44 days long and the maximum eclipse time at equinox is about 1.2 hours as shown in Figure 7-21. The proportion of time that the satellite is in eclipse is approximately 0.009. By utilizing a satellite in both the East and West stations, continuous operation of the DWS is possible during the periods of solar eclipse. Thus, the probability that the system is operational is the probability that both East and West are operational and that there is an eclipse, or that either east or west is operational and there is no eclipse; i. e.,

$$P \{ (EW) \bar{E} \cup (EUW) \bar{E} \} \geq p \quad (7-2)$$

where P = some preselected level of operational capability

E = event that East station is operating

W = event that West station is operating

\bar{E} = event of an eclipse.

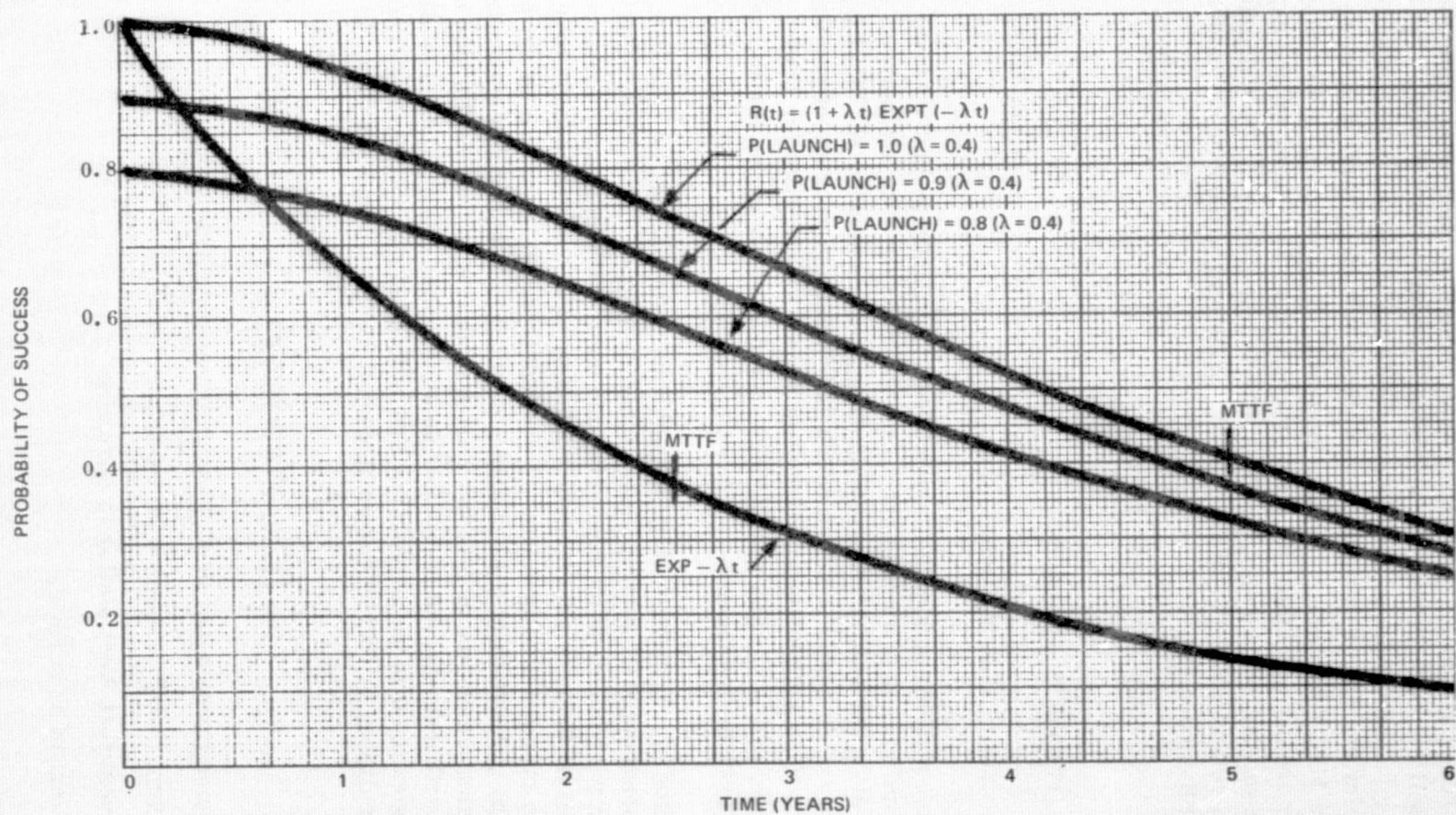


Figure 7-20. Reliability of DWS Satellite

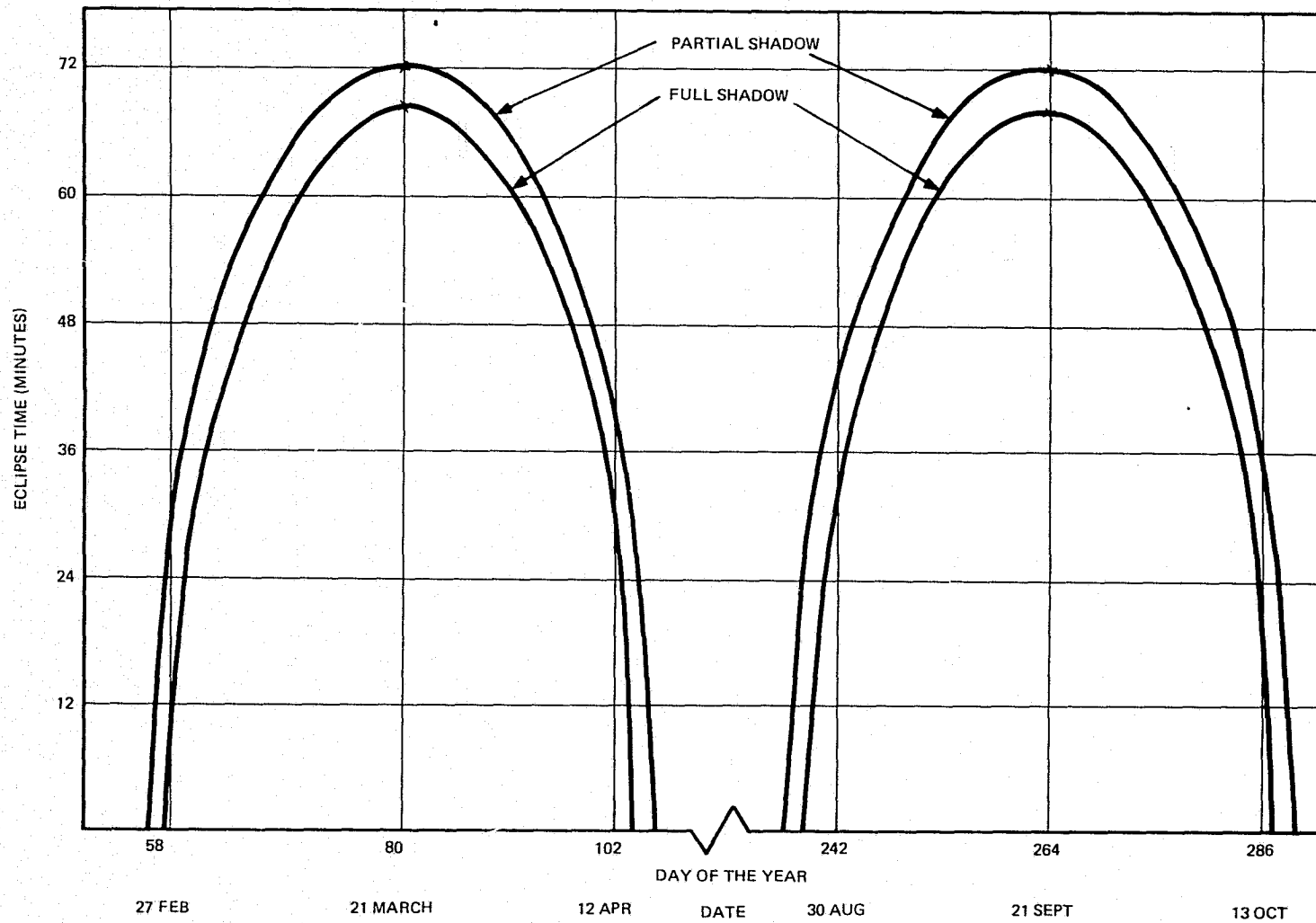


Figure 7-21. Solar Eclipse Period

Then, during the two eclipse cycles, Equation (7-2) becomes

$$P \{EW\} \geq p \quad (7-3)$$

which is the situation where both satellites are required to be operational with a probability greater than some selected value p . However, whenever there is no eclipse, Equation (7-2) becomes

$$P \{EUW\} \geq p \quad (7-4)$$

The system reliability as a function of launch intervals is shown in Figures 7-22 and 7-23 for Equations (7-3) and (7-4), respectively. Thus, if the DWS satellite system reliability or, equivalently, the probability of success is required to be greater than or equal to 0.9, and the requirement is that both East and West Stations be operational, the satellites will have to be launched with approximately 1.1 years between launches while, if the requirement is that either East or West stations be operational, there may be approximately 2.2 years between launches. It is readily apparent that for a DWS satellite system reliability of 0.9 or greater, the launch interval for the requirement that both East and West stations be operational is half of the interval when the requirement is that either East or West stations be operational. The launch intervals are inversely proportional to cost and the more stringent requirement based on Equation (7-3) will cost approximately twice as much as the less stringent requirements based on Equation (7-4).

Consider the criteria given by Equation (7-2) with $p = 0.9$ and $\epsilon = 0.0095$, and a launch interval of 2 years. Assume that when a satellite is 6 years old or older, it will be turned off and no longer considered as part of the DWS satellite system. Further, assume that a satellite has just been launched into East station and, under steady state conditions, the satellite in West station is 2 years old. Then, after 2 years, and just prior to launch of another satellite into West station, there are satellites which are 2 and 4 years old in East and West stations, respectively, and

$$P \{E\} = R(2) = 0.8088$$

$$P \{W\} = R(4) = 0.5249$$

(7-5)

$$P \{EUW\} = 1 - (1 - R(2))(1 - R(4)) = 0.9092$$

$$P \{EW\} = R(2) * R(4) = 0.4245$$

Then $P \{(EW)\epsilon U(EUW)\epsilon\} = 0.4245 * 0.0095 + 0.9092 * 0.9905 = 0.9044$ and a launch interval of 2 years will satisfy the criteria for a preselected probability of success of 0.9. As would be expected, since the probability of an eclipse occurring at any time is small, the system reliability is almost the same as requiring EUW.

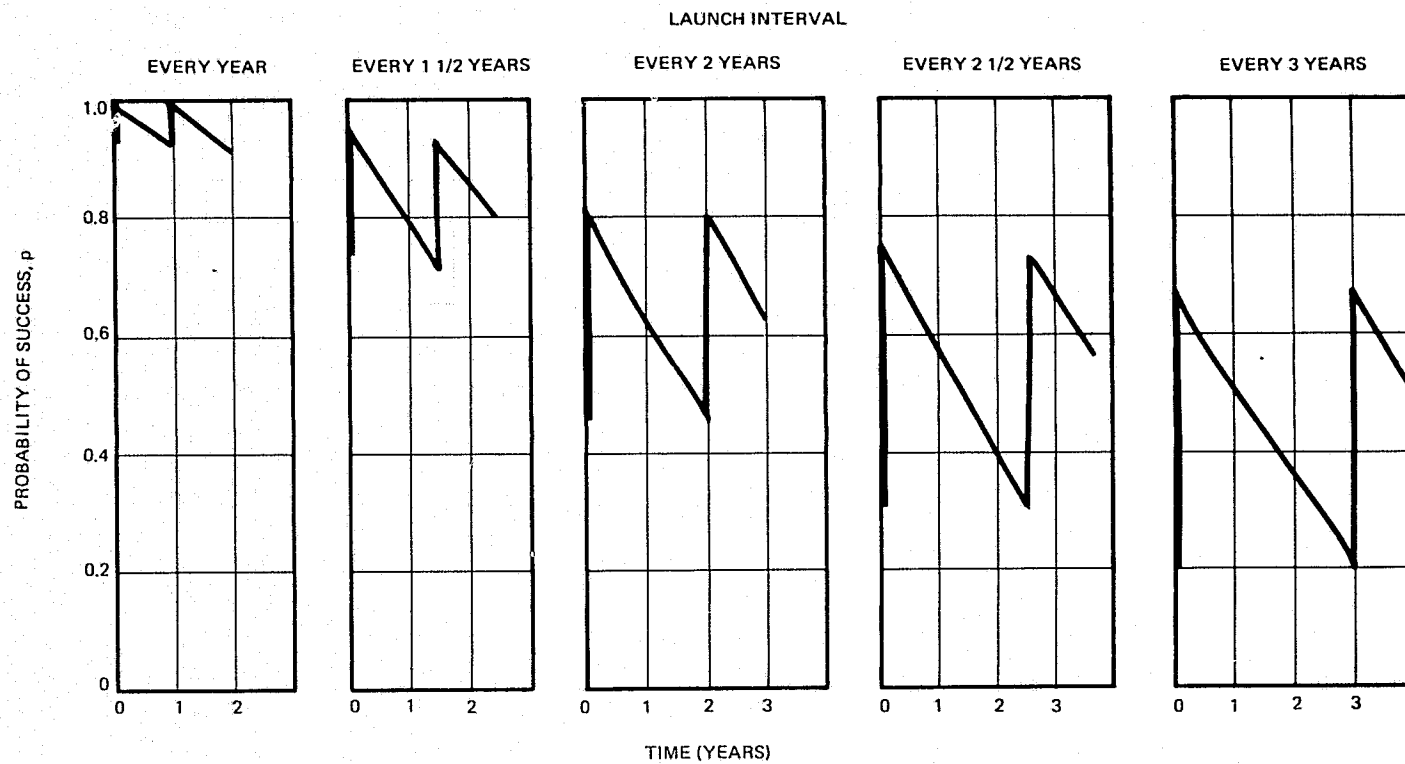


Figure 7-22. DWS Satellite System Reliability, East and West Stations Operational

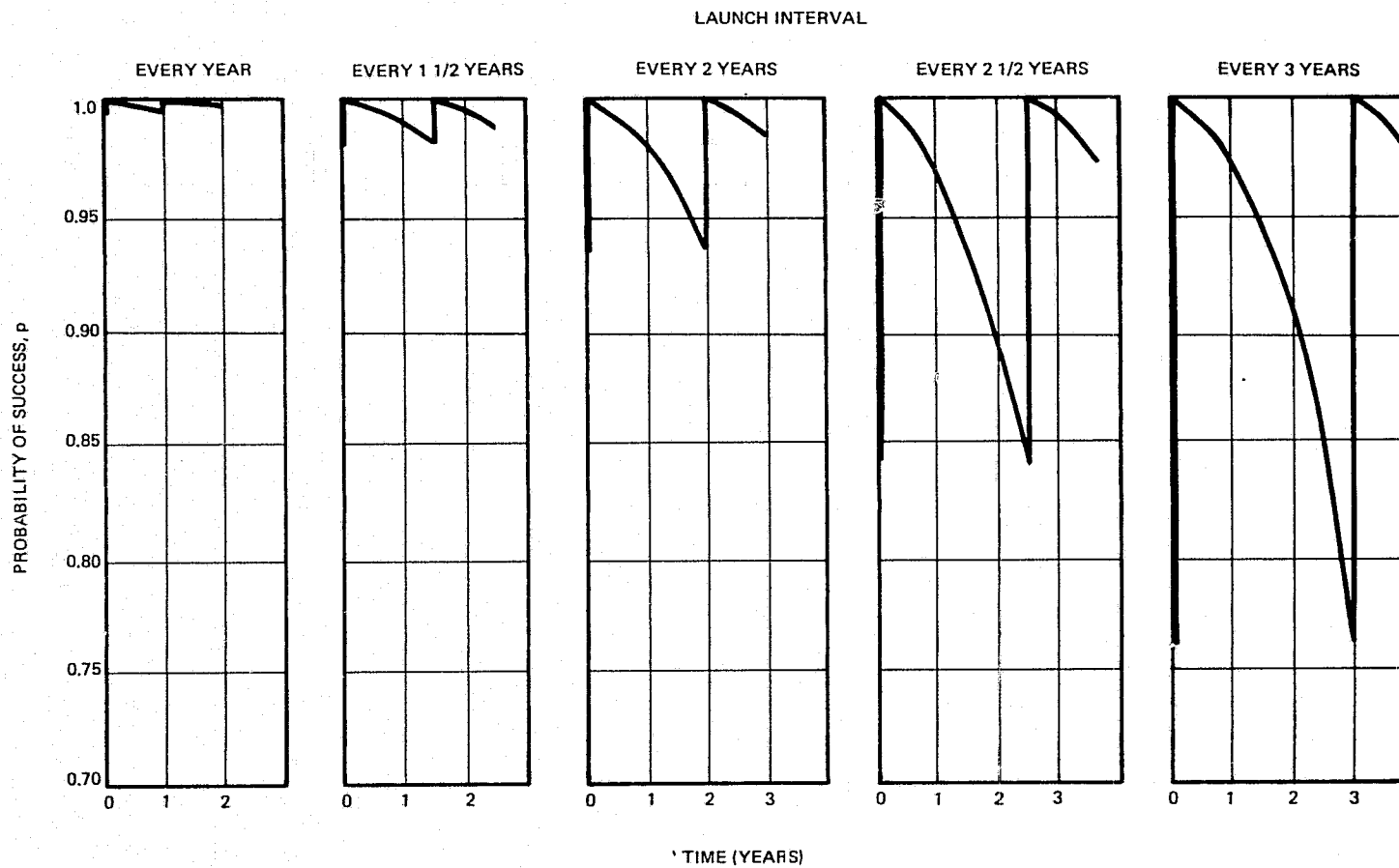


Figure 7-23. DWS Satellite System Reliability, East or West Stations Operational

During the early life of the system in the transition to steady-state, the interval between launches must be adjusted to maintain the system reliability at the predetermined level which is the system lifetime goal in the steady-state period. A method for optimizing launch times is to launch at intervals such that minimum system reliability prior to each launch is equal to minimum system reliability during the steady-state period. For example, assume that the protoflight satellite is launched into the East station and that after system test and fabrication and test, flight unit #2 is launched into West station τ years later. The time to launch the next satellite (into East station) is determined by finding the value of t , such that

$$[R(t) * R(t-\tau)] \bar{C} + [1 - (1-R(t))(1-R(t-\tau))] \bar{C} = 0.9. \quad (7-6)$$

Letting $\tau = 1$, the value $t = 3.372$ was determined by an iterative process. This procedure is repeated until the steady state condition is reached when the satellites are launched approximately two years apart. Figure 7-24 shows the time for subsequent satellite launches to maintain the preselected value of the conditional probability that the system is operational, given that the launch is successful.

To estimate the number of satellites that must be procured for the program, it is necessary to consider the probability of launch. To be more precise, Equation (7-2), which defines the DWS satellite system reliability criteria, should have been expressed as a conditional probability

$$P \{ [(EW) \bar{C} U(EW) \bar{C}] | L \} \geq p \quad (7-7)$$

where L is the event of a successful launch. It is anticipated that if a launch fails, a second launch will be immediately attempted and a spare satellite will be immediately available for launching. The probability of launch determines the total number of satellites that must be procured. For example, if six satellites are required in orbit and the probability of launch $P\{L\} = 0.85$, then seven satellites must be procured.

7.11 TECHNOLOGY REQUIREMENTS

7.11.1 Introduction

To meet the basic requirement of routing warning messages to the general public, the DWS satellite must generate a high level of EIRP during an expected life of five years. Since the satellite transmitter, including power combiners, and antenna are the major subsystems directly affecting the satellite EIRP, they merit the highest priority in improving their technological state of the art. This paragraph briefly addresses the technological aspects of these subsystems in the frequency band ranging from 500 to 1000 MHz. Regardless of which type of transmitter is used, the high-power requirement for the DWS satellite, together with its associated high heat dissipation, places a large stress on the thermal control subsystem. A well designed thermal control capable of dissipating the heat is essential for prolonged transmitter life.

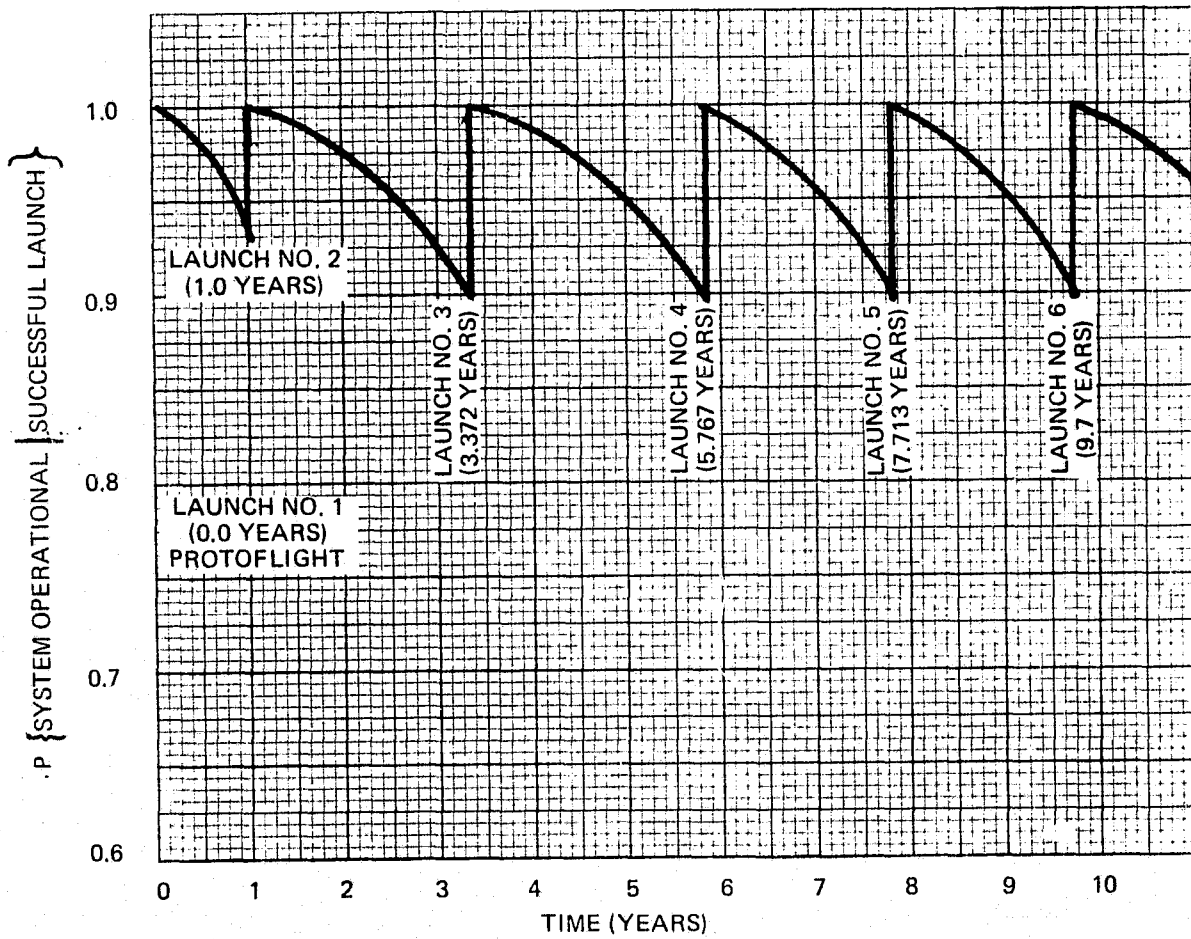


Figure 7-24. DWS Satellite System Launch Strategy

7.11.2 High Power Transmitters

As satellite technology evolves toward higher power, the efficiency of the transmitter assumes even greater importance. Better efficiency implies greater power per pound of spacecraft, since (1) the solar array can be made smaller for a given EIRP level, (2) the reduction in generated heat enables the use of a lighter thermal control subsystem, and (3) the reduction of required BOL power implies reduced power subsystem weight.

In the frequency band of interest three basic types of transmitters may be used; transistors, gridded tubes, and microwave-type tubes. Of the microwave tubes, the Crossed Field Amplifier (CFA) is best suited for applications where power per unit weight and volume and high efficiency are important. Since bandwidth is not a critical parameter, the CFA is the primary microwave tube considered.

In general, the following statements can be made about the efficiency of the three types of transmitters:

1. Range of overall transmitter efficiencies is 40 to 70 percent
2. A high-efficiency amplifier is usually associated with relatively low gain
3. Transmitter efficiency for multiple-carrier operation is lower than that of single-carrier operation
4. For a given supply power, transmitter efficiency goes down with reduced drive level. It is maximum when transmitter operates at saturated level
5. Efficiency and gain can be expected to improve with narrow band operation.

7.11.2.1 Transistor Amplifiers

Advances in solid-state power amplifier technology have brought these devices to a point where, in many instances, they have become competitive with tube-type power amplifiers. Solid-state transmitters producing 80 watts of RF power have been used in the ATS-F program, and they have potentially longer lifetimes than any tube-type transmitter. In the frequency band of concern, a single transistor device offers as much as 50 watts CW with a collector efficiency greater than 60 percent. It is projected that in the near future individual stages can be combined to yield as much as 1000 watts CW. With this level of output power, a solid-state transmitter obviously can meet the DWS repeater baseline power requirement. At 700 MHz, the projection for transistor-device capabilities over the next few years indicates a device output of 75 watts at a stage efficiency of 65 percent or greater.

To obtain a high collector efficiency, the transistor amplifier operates in the class-C mode. For single-signal operation, maximum efficiency is obtained when operation is near the saturated output level. The maximum attainable efficiency decreases as the number of input carriers increases. The efficiency, however, remains relatively constant over a wide range (3-5 dB) of input drive levels before falling off rapidly at low input drive levels. This makes the transistor device more attractive than other types of devices for multiple-carrier operation. If the transmitter efficiency could be held high and relatively constant over an 8-dB dynamic range of output power, multiple-carrier operation would become a very promising alternative.

Overall amplifier efficiency is defined as the ratio of the output RF power to the total input power. Factors such as RF power required, maximum power of the individual devices being summed, and specific implementation techniques used to combine the power of the individual devices affect the overall amplifier efficiency.

Solid-state power devices are low-gain devices. The gain per stage for a 50-watt device is between 10 and 12 dB for a common-base configuration and 6 to 8 dB for a common-emitter configuration. With these low-gain devices the driver power required for the final stages, and the efficiency at which this driver power is generated, cannot be ignored. Because most driver and pre-driver stages are operated in their linear region (low collector efficiency), these stages could require tens of watts of dc prime power.

To achieve high-level power from multiple transistor stages, power combiners must be used. Losses in the power combining section of the amplifier must be minimized because they subtract directly from the output power. Amplitude and phase imbalances also detract from the output and must be compensated for by more power from the transistors. The most efficient way of combining a relatively large number of individual stages utilizes a Wilkinson summer which can be built to have less than 0.5-dB insertion loss and greater than 20-dB isolation over a 10 percent frequency band. Also, there is usually a regulator which is less than 100 percent efficient between the satellite solar array and the transistor power amplifier. Work is being done on connecting the transistor transmitter directly to the solar array to circumvent the need for a regulator. Based on the ongoing development efforts and the present capabilities, an estimation was made of the 1980 state-of-the-art for space applications of solid-state transmitters. The estimated maximum capability is an RF power of 150 watts at an efficiency of 45 percent.

In a solid-state transmitter, the life of a high-power transistor is related closely to the transistor junction temperature. A high junction temperature results in a short mean time to failure; whereas, a low junction temperature can result in a lifetime in excess of 500,000 hours. Low overall thermal resistance is needed for a high-power transistor if junction temperature is to be minimized for increased operating life. A well designed high-power transistor amplifier should also minimize the possibility of catastrophic hot-spot formation, or second breakdown, with a minimum degradation of RF performance.

7.11.2.2 Gridded Tubes

Gridded tubes are also applicable; although, with the exception of certain developmental work at GE, little has been done to develop space-qualified high-power hardware. They can deliver power far in excess of that needed for the DWS requirement. They are used extensively as transmitters and repeaters in the UHF broadcasting field. The devices are characterized by high efficiency for Class C operation (in excess of 70 percent) and higher gain than that of a transistor device. The gain of the tube may be improved for narrow band operation. Since a gridded tube maintains reasonable efficiency when operated linearly, it is also a candidate for multiple-carrier amplification.

7.11.2.3 Microwave-Type Tubes

There are three types of microwave tubes suitable for satellite transmitters; however, only one of these is a candidate in the 500 to 1000 MHz frequency band. The TWT is a strong and proven candidate at higher frequencies, but its high weight and size are not competitive in this band. The klystron, although not presently used as a satellite amplifier, can be eliminated on the same basis. Although the CFA has not demonstrated a sufficiently long lifetime for use in a satellite mission of several years, it is the best candidate of the three because of its high efficiency with respect to both power and weight.

The CFA is characterized by high efficiency (70 percent) and low gain. Enhancement in CFA gain is usually brought about with an associated degradation in efficiency; however, for narrow band operation some increase in gain with minimum loss in efficiency can be expected. An efficiency of 45 percent was used in the computer model.

Although linear beam tubes can be operated below saturation with low efficiency, the CFA cannot because noisy oscillation in this mode renders it impractical. At a high drive level, the signal suppresses the noise and the output reaches a limiting value determined by the dc input power. Therefore, the only feasible operation point of the CFA is at saturation.

The potential lifetime of a CFA is longer than that of a gridded tube. The lifetime of both devices is determined largely by random failure and cathode wearout. Random failures relate mostly to manufacturing quality and field application problems, but cathode wearout is a design consideration. If the two failure modes are approximately equally likely for the CFA and gridded tube, the gridded tube inherently has a shorter life than the CFA. The mechanism of aging in the gridded tube is not only the "using up" of the cathode but also the contamination of the grid or other portions of the tube by particles emanating from the cathode. The cathode wearout failure mode in an oxide cathode is caused by the gradual loss of the oxide coating. To prolong the CFA life, recent models employ cold cathodes of several varieties. The cathodes utilize either pure metal or cold oxides. The pure metal type, such as platinum, has no wearout mechanism other than erosion. The cold-oxide types wear out through disassociation of

the oxide. Replenishment mechanisms such as a dispenser cathode or a matrix cathode may be used to preserve the oxide either continuously or periodically. With these techniques, some of which are under development, the theoretical life expectancy of the CFA cathode is expected to show considerable improvement with the potential achievement of 100,000 hours.

7.11.3 Antennas

The need to provide the coverage area with a high EIRP and minimum spillover and interference with noncoverage areas has led to the requirement for high-gain, multibeam spacecraft antennas with low sidelobe levels.

Among its diverse functions, a multibeam antenna with narrow beams provides maximum gain over the target area. This factor can be used to increase communications capability for a given satellite power level or to minimize overall system cost. The reduced costs result from either reducing the complexity of the ground terminal or by providing less RF and prime satellite power.

To date, most of the R&D effort in multibeam antennas has been focused on the frequency regions above 4 GHz. The exception is the ATS-F program which utilizes a 30-foot (9.14-meter) deployable dish in conjunction with UHF radiator feeds to produce a coverage beam. Further R&D effort would be required to develop a deployable multibeam antenna system.

There are three basic implementations for multibeam antennas: the reflector with offset feeds, the lens, and the phased array. The latter two, because of weight or weight-gain characteristics, are not suitable for UHF application.

In general, the reflector is the simplest approach for six or fewer beams. There have been several programs in the past relating to multibeam antennas using reflectors. Unfortunately most of them concerned themselves with frequencies well above 1000 MHz. Some of these programs were primarily involved with beam-shaping using a multitude of narrow pencil-beams. The main problem was that of achieving high gain with low side-lobes. Other programs involved the employment of offset feeds to achieve shaping. Only one program involved a reflector sufficiently large that it had to be partially folded.

In conclusion, it appears that there is not sufficient experience to meet the requirements of the antenna subsystem of the proposed DWS program. R&D effort is a prerequisite to determine if such a subsystem is feasible and economical.

SECTION 8 - COST ANALYSIS

8.1 INTRODUCTION

This section presents parametric life-cycle cost estimates for both the baseline satellite and terrestrial system as well as the costing procedures and techniques. The costs were consistently made in the three-phase life-cycle format: research, development, test, and evaluation (RDT&E); investment; and operation. The development of the parametric cost estimates for both baseline DWSs focuses on the identification of the relevant cost elements, the necessary parameters and basic assumptions, the structuring of these elements and parameters into a representative model of the actual system costs, and derivation of the estimated cost of each element. The cost elements are categorized as nonrecurring, unit recurring, and annual recurring, which are consistent with the three phases of the life-cycle format and the work breakdown structure (WBS) used to define each baseline system. The structured relationships give the capability to develop and assign costs to the several different DWS subsystems each with its own peculiar characteristics. The estimated parametric costs must be valid relative estimates upon which comparable resource requirements can be based. It is emphasized that this cost analysis will predict resource requirements and not prices. In parametric analyses, the item is not well defined; in fact, these analyses often are performed to help define the item and therefore the objective is consistency and compatibility within the set of analyses. It is desirable to have the approximate magnitude of cost, but, realistically, the precise magnitude is not attainable.

Identification of the relevant cost elements, structuring of these elements, and estimating procedures will be discussed in turn. All aspects of program cost have been considered for the research, development, test, evaluation, and acquisition of the DWS as well as for ten years of operation, to a depth consistent with the study requirements. The primary objective of this study is to make a comparative analysis of the baseline systems which meet stated requirements, by identifying promising configurations and the cost sensitivities associated with each.

8.2 BASIC COST ASSUMPTIONS

The following basic cost assumptions and ground rules are necessary to derive the life-cycle costs and will provide the basis for the cost analysis. The cost ground rules which were furnished by NASA are incorporated into this list of assumptions.

1. All costs will be presented in constant FY 1974 dollars. Estimates based on costs for other than FY 1974 will be converted to FY 1974 dollars using the procedure described in Paragraph 8.4.3.

2. An estimated 1980 technology base was assumed.
3. The Initial Operating Capability (IOC) is required in the early 1980's.
4. The baseline operational program extends for 10 years.
5. RDT&E funding is concluded after test and evaluation of DWS (the protoflight satellite is used for test for the satellite DWS).
6. Cost of procurement and launch of satellites will be keyed to the launch strategy required to maintain the system reliability developed in Paragraph 7.10.
7. Satellites will be launched into geostationery orbit by a space shuttle plus an orbit-to-orbit stage (OOS) vehicle.
8. Procurement of ground segment equipment and facilities will be time phased over 5 years. The priority of installation will be to maximize population coverage in accordance with the recommended geographical implementation phasing, Paragraph 9.3.
9. Learning curves will be used to estimate equipment costs when procurement of large quantities of equipment is expected.
10. New facility requirements for both ground and space segments will be minimized.
11. Uniform annual costs and present value discounted costs will be computed using a 10-percent interest rate. Future year costs are estimated in constant FY 1974 dollars and do not include a factor to estimate inflation.
12. Salvage values are not considered for the DWS ground segment. For the space segment, salvage values will be based on usable satellite life remaining at the end of the 10-year period of operations.
13. Satellite mean time to failure is assumed to be 5 years and its maximum useful life is assumed to be 6 years.
14. Leasing from commercial sources of the dedicated communication lines required in the terrestrial network is assumed to be the least cost procedure.

15. The electronic equipment is assumed to have a useful life of 10 years except for the transmitters/receivers of the data collection platforms (DCPs). The assumed life for these units is 5 years.

8.3 COST ELEMENTS

8.3.1 Cost Categories

The following basic cost categories are defined and used throughout the cost analysis. Within each category there are both direct and indirect costs. The indirect costs are those normally associated with overhead such as administrative services, financing, training, system test and evaluation, and technical management and engineering.

8.3.1.1 Nonrecurring Cost

These costs relate to the RDT&E phase and are primarily associated with the research and development of the DWS to a point where the system has an IOC. These costs are necessary to develop and manufacture the system components and preproduction prototype items which are not quantity related and are necessary to demonstrate in test programs that the developed system meets the DWS design requirements. It also includes basic engineering design and development; developmental support and tests; development and manufacture of special tooling; auxiliary ground, bench and special test equipment; and necessary facilities and training to support the DWS through the completion of the RDT&E phase.

8.3.1.2 Unit Recurring Costs

These costs relate to the investment phase and are primarily associated with the acquisition of equipment and facilities as well as the initial stocking of spares/repair parts, and any special test/maintenance equipment required to support the operations program. These costs will also include all additional costs such as first transportation, installation, and acceptance testing required to make each item operational as part of the system. These recurring investment costs will be expended on a time-phased and repetitive basis for the acquisition of the DWS equipment and facilities.

8.3.1.3 Annual Recurring Costs

These costs, incurred after the acceptance of the DWS equipment and facilities, are associated with the operation of the system and the maintenance of the equipment and facilities. These costs are (1) operations costs, which include command and data acquisition; data processing and analysis; technical management and engineering; and field station operations; and (2) maintenance costs, which include labor and materials for maintenance of facilities and equipment; and communications costs.

8.3.2 Work Breakdown Structure

The Work Breakdown Structure (WBS) is a standardized division of the DWS system into components, subcomponents, and tasks. This is represented by a structure displaying the system in levels of subcomponents and subtasks which can be consolidated into higher levels of component aggregation. The WBS provides the consistent format required for the system definition, assembly of cost inputs for the cost analysis, and task assignment in the implementation plan. The WBS format and elements must also be consistent with the program/budget structure of the responsible agency.

The typical WBS was analyzed and modified to develop a consistent format that could be used for the system definition, the cost analysis and the implementation plan. The format established a positional coding system that identifies a unique system component for which costs can be developed and responsibilities can be assigned for implementation. This WBS format is shown in Table 8-1.

At level 1, designated by the first code position, the cost categories are identified. At levels 2 and 3, designated by the 2nd and 3rd and by the 4th and 5th positions respectively, the DWS major component systems and the subcomponent systems are identified. The listing at levels 2 and 3 apply uniformly to each of the three different cost categories. For example, the five-digit format 1-05-02 identifies the activities which are associated with the development of the equipment, procedures, facilities, et cetera, for the spotter network of the collection system, and are designated as nonrecurring costs. These funds may, however, be R&D, equipment and facilities, operation and maintenance, et cetera. The five-digit format 2-05-02 identifies the activities associated with the actual procurement of the equipment/facilities for the spotter network of the collection system and which are designated as unit recurring costs.

The format digits 00 may be used at any level (except level 1) to designate the management function. Thus, the format 1-01-00 identifies the management activities for the development (nonrecurring costs) of the satellite system while the format 1-01-01-00 identifies the management activities associated with the development of the spacecraft of the satellite system.

Level 4 generally identifies functional or work related areas which are different for each of the cost categories. These functional elements are illustrated in Table 8-2, which contains elements of a typical breakdown for each of the cost categories. While this breakdown shows an extension to the 5th and 6th level, not all of the elements are applicable to every one of the subcomponent systems.

Table 8-1. Format for DWS Program Work Breakdown Structure (WBS)

WBS Element	Level	WBS Identity No.
Nonrecurring Costs	1	
Satellite System Management	2	1-01-00
Spacecraft	3	1-01-01
Launch Services	3	1-01-02
Auxiliary Ground Equipment	3	1-01-03
Ground Terminals Management	2	1-02-00
Weather Service Office Terminal	3	1-02-01
Central Control Station	3	1-02-02
Terrestrial Network Management	2	1-03-00
Telecommunications	3	1-03-01
Broadcasting Facilities	3	1-03-02
Public Information and Warning System		
Management	2	1-04-00
Home Receivers	3	1-04-01
Local Community Receivers	3	1-04-02
Official Receivers (Federal)	3	1-04-03
Collection System Management	2	1-05-00
Data Collection Platforms	3	1-05-01
Spotter Network	3	1-05-02
Reconnaissance Aircraft	3	1-05-03
* * *		
Unit Recurring Costs	1	
Satellite System Management	2	2-01-00
Spacecraft	3	2-01-01
Launch Services	3	2-01-02
Auxiliary Ground Equipment	3	2-01-03
Ground Terminal Management	2	2-02-00
* * *		
Annual Recurring Cost	1	
Satellite System Management	2	3-01-00
Spacecraft	3	3-01-01
Launch Services	3	3-01-02
Auxiliary Ground Equipment	3	3-01-03
Ground Terminal Management	2	3-02-00

Table 8-2. WBS Functional Areas

WBS Element	Level	WBS Identity No.
Nonrecurring Costs	1	
Component System	2	1****
Subcomponent System	3	1****
Research Design and Fabrication	4	1****01
Integration, Testing, Qualification	4	1****02
Unit Recurring Costs	1	
Component System	2	2****
Subcomponent System	3	2****
Major System Equipment	4	2****01
Secondary Items	4	2****02
Installation	5	2****02-01
Acceptance Testing	5	2****02-02
Initial Spares/Repair Parts	5	2****02-03
Test/Maintenance Equipment	5	2****02-04
Transportation	5	2****02-05
Support Facilities	4	2****03
Land	5	2****03-01
Site Preparation	5	2****03-02
Buildings	5	2****03-03
Fencing	5	2****03-04
Power Plants	5	2****03-05
Roads	5	2****03-06
Antenna Foundations	5	2****03-07
POL Storage	5	2****03-08
Water and Sewage	5	2****03-09
Auxiliary Ground Equipment	5	2****03-10
Annual Recurring Costs	1	
Component System	2	3****
Subcomponent System	3	3****
Operations (2)	4	3****01
Command and Data Acquisition (2)	5	3****01-01
Data Processing and Analysis (2)	5	3****01-02
Technical Management and Engineering(2)	5	3****01-03
Field Station Operations (2)	5	3****01-04
Rents	6	3****01-04-01
Utilities	6	3****01-04-02
Transportation	6	3****01-04-03
Consumables	6	3****01-04-04
Operations Personnel	6	3****01-04-05
System Tests	6	3****01-04-06

Table 8-2. WBS Functional Areas (Cont'd.)

WBS Element	Level	WBS Identity No.
Annual Recurring Costs - Subcomponent System (Continued)		
Maintenance and Repair (2)	4	3****02
Facilities (2)	5	3****02-01
Labor	6	3****02-01-01
Materials	6	3****02-01-02
Equipment (2)	5	3****02-02
Labor	6	3****02-02-01
Materials	6	3****02-02-02
Communications (2)	4	3****03
Line Charge (Mileage)	5	3****03-01
Terminal Connections	5	3****03-02
Local Loop Service	5	3****03-03
<p>(1) The asterisks represent the WBS identity numbers for the component and sub-component systems shown in Table 8-1.</p> <p>(2) Corresponds to the NOAA Program Budget Structure Levels 2 and 3, effective with FY 1974.</p>		

8.4 COST ESTIMATION METHODS

8.4.1 Introduction

In the feasibility study of using satellites for a DWS, the primary purpose of the cost estimates is to perform a cost-tradeoff between competing alternatives. The cost estimates will be developed based on the equipment and personnel manning requirements which will be derived from the definition of a technically workable system. The cost estimates, together with the WBS and the time-phased system implementation plan, will be used to produce a time-phased funding plan.

Presented herein are the methods used for a cost comparison between the two systems. First, two different cost comparison techniques are presented, and then the detailed technique for estimating the costs of the major system components are defined. To avoid too much detail in the main text of this report, several of the cost estimating techniques are contained in the appendices. For the reader interested in the derivation of all the cost factors, it will be necessary to refer to these appendices.

8.4.2 Alternative Systems Cost Comparison

The following paragraphs describe the two methods (including the advantages and limitations of each) by which the costs of two alternative systems can be compared. One method uses the total life-cycle cost (LCC) of the system expressed in constant dollars and includes the nonrecurring cost, unit recurring cost, and the annual recurring cost for a fixed period of years. This method does not include the considerations of the time value of money and is the only type of comparison that may be used when there is no funding schedule. This method requires that for a valid comparison the two systems are compared over the same number of years of operation. The other method derives the uniform equivalent annual cost by which two systems can be compared. This method requires a funding schedule, considers the time value of money, and may be used to compare two systems with different operational lives. The time value of money does enter into the standard engineering economy calculations and may make a considerable difference in determining the choice among alternatives.

8.4.2.1 Total Life-Cycle Cost Method

For the cost tradeoff between alternative systems, a basic planning horizon is selected over which the total system can be costed. For determining the total life-cycle cost, the planning horizon should be of sufficient duration that costs will be repeated for replacement assets and the least common multiple of the lives of the various assets involved. In this manner it is possible to reconcile the total life-cycle costs with periodic funding requirements. The estimated life of the electronic equipment is assumed to be 10 years, except for the DCP equipment which has an

expected life of 5 years due to its exposure to hazards. After 10 years of service, electronic equipment may still be operational, but because of obsolescence, may have to be replaced. Buildings and towers, if properly designed, constructed, and maintained, should have a life cycle of 30 years. The life of a communication system will depend upon many factors such as new philosophies of operation, methods, techniques, and strategies that may make the facilities of the system undesirable or obsolete. In this era of rapidly developing technology, the useful life a communication system, which depends so heavily on a communications satellite, cannot be expected to exceed 10 years. Therefore 10 years is chosen as the operational period of the alternative system over which the cost comparison will be made.

Based on the defined cost categories and the subcomponent system contained in the WBS, the total life cycle cost model is:

$$DWS \$ = A + \sum_i B_i S_i + C Y$$

where:

DWS \$	Total system cost
A	Nonrecurring cost
B_i	Unit recurring cost for subsystem i
S_i	Number of system i units required initially or as replacement during span of planning horizon
C	Annual recurring cost
Y	Number of years in planning horizon

This expression for the total system cost over a given period of time represents the total life-cycle cost which includes the cost of developing the system, the initial deployment of the system, replacing units in the system, and operating and maintaining the system for the specified life-cycle.

8.4.2.2 Equivalent Uniform Annual Cost Method

The time value of money relates directly to the comparison of expenditures made at different times. There are three categories of expenditures: nonrecurring costs, those one time costs which are used to develop the system, generally long before any benefits are derived; unit recurring costs, procurement costs used to acquire the system components and to replace major components which have an expected life shorter than the system life; and annual recurring cost, those costs required to operate and maintain the system. There also may be disposal costs which are usually relatively small. The accepted procedure for combining the three cost categories when a funding plan is known is to employ the present worth (value) concept. Present worth comparisons are always theoretically sound, although, it is often difficult to determine the necessary estimates, especially in selecting a

critical rate of discount. The Office of Management and Budget recommends that all federal programs use a discount rate of 10 percent (Reference 10). However, the present worth method would have to tabulate the least common multiple of the estimated lives of the two alternatives. For example, if the life of one alternative was 6 years and the life of the other 5, a 30-year period would have to be tabulated before reaching the point where the alternatives give equal years of service. An accepted procedure to compare nonuniform series of expenditures over different periods of expected life, and where money has a time value, is to reduce the expenditure for each alternative to an equivalent uniform annual series of payments.

For example, suppose a company wanted to buy a machine to produce items for sale and the two alternatives are:

	Machine A	Machine B
Initial Cost	10,000	9,000
Annual Operating Cost	500	1,000
Useful Life	5	6

Assume that the company borrows the money at 10 percent interest and repays the amount over the expected life of the machine. There is no salvage value. The amount of money which the company would pay annually to repay the loan is shown as the capital recovery cost. The uniform annual cost is determined by multiplying the initial cost by the capital recovery factor* (crf) for the appropriate useful life and adding the annual operating cost. In this case, the crf for (10%, 5 years) is 0.26380 and for (10%, 6 years) is 0.22961. The uniform annual cost for each machine is then determined as follows:

Machine A

Capital Recovery Cost $\$10,000 \times 0.26380$	\$2638
Annual Operating Cost	<u>500</u>
Uniform Annual Cost	\$3138
Total Cost Over 5 Years, 5×3138	\$15690
Less Cost $10,000 + 5 \times 500$	<u>12500</u>
Interest	3190

*The definitions of this and other cost analysis terms are contained in Appendix J.

Machine B

Capital Recovery Cost $\$9,000 \times .022961$	\$2066
Annual Operating Cost	<u>1000</u>
Uniform Annual Cost	\$3066
Total Cost Over 6 Years, 6×3066	\$18396
Less Cost $9,000 + 6 \times 1000$	<u>15000</u>
Interest	3396

Thus, the decision would be to purchase Machine B since the uniform annual cost for this machine is less than for that of Machine A. The value of the uniform annual cost is also the amount of money that the company must recover from the operation of the machine to break even (a fixed amount of profit, e.g., dividends to stockholders, may be included as an item of annual operation) at the specified interest rate of 10 percent.

In the example, the initial cost was concentrated at the beginning of the time period over which the costs were to be spread. For large complex systems, such as the DWS, it is usually necessary to expend money for a number of years prior to the time that benefits are expected. Thus, it is necessary to combine the present worth method and the uniform annual cost method to arrive at an equivalent uniform annual cost that is the basis for cost comparison between competing alternatives. First, it is necessary to accumulate expenditures, each discounted to its present worth at a specified interest rate. Secondly, it is necessary to determine the future worth of the expenditures at the beginning of the benefit period, and finally to use the crf to determine the uniform annual cost. The end of the year convention will be used wherein the interest will be accumulated at the end of the year.

8.4.3 Inflation Factors

The cost estimates are derived from many varied reference documents which have been developed over the past few years. To adjust all costing data to FY 1974 dollars, it is necessary to adjust the cost for a given item from the year in which the cost estimates were valid to the year 1974. The Cost Estimation Relationship (CER) for the spacecraft cost, which is described in the next paragraph, was based on historical costs converted to 1970 dollars. Reference 11, which describes the development of the CER, also describes a procedure by which the historical costs were converted to 1970 dollars. Using the procedures and results described in Reference 10, the inflation factors for the years subsequent to 1970 were developed. For the period prior to 1970, the inflation factors taken from Reference 10:

Years	% Rate of Change
1965 to 1966	3.0
1966 to 1967	3.5
1967 to 1968	4.0
1968 to 1969	6.0
1969 to 1970	7.0
1970 to 1971	6.0
1971 to 1972	4.5
1972 to 1973	8.0
1973 to 1974	10.7

8.4.4 Space Segment Cost Estimating Relationship (CER)

The cost estimate for the DWS satellite is based on a CER described in Reference 11. The estimated cost derived by this CER is based on the weight of the spacecraft and the value of a parameter known as "equivalent units". This parameter represents both nonrecurring and unit recurring effort. The nonrecurring effort includes design and development, thermal-mechanical test unit, engineering unit, prototype unit, and redesign effort. The unit recurring effort represents the acquisition of the required number of flight units and spares. Using this CER, the total cost of the RDT&E effort and the acquisition of the required number of flight units and spares is derived. By dividing the total cost by the number of equivalent units, the spacecraft unit cost is determined. This unit cost is used to determine the amount of RDT&E funds required as well as the replacement unit cash flow. The reliability of the spacecraft will impact the cost by establishing the launch schedule required to maintain the required system reliability. The reliability of the launch vehicle will impact the cost by establishing the expected number of spacecraft that must be procured and launched to complete the launch schedule.

The CER from Reference 11 adjusted to estimate the spacecraft cost in millions of 1974 dollars based on the weight (WT) of the spacecraft in kilograms and the number of equivalent units (EU) of nonrecurring and unit recurring effort is given by the expression:

$$\text{Cost} = 0.4003 (\text{WT})^{0.6158} (\text{EU})^{0.9684}$$

For example, to consider the baseline satellites DWS where the weight of the spacecraft was determined to be 3650 kilograms (8048 pounds). A considerable amount of R&D will be required for technological work in high powered hardware, multiplexing equipment, and amplifier tubes, as well as the design and development of a large spacecraft antenna for downlink transmissions. For the spacecraft of this baseline satellite system, it will be necessary to consider design inheritance to more correctly

determine the number of equivalent units which represent the nonrecurring effort. Further, it is desired to test the DWS with a protoflight unit in geostationary orbit. Subsequent to the test, the protoflight unit will become an operational unit. Based on the results of this test, some redesign may be accomplished to improve subsequent flight units.

The values of the EUs applicable to the DWS satellite are adapted from Table V of Reference 11. Values for the effort without inheritance are:

Nonrecurring Effort:

Design and Development Without Inheritance	3.0	
Thermal/Mechanical Test Unit	0.2	
Engineering Unit	0.7	
Protoflight Unit	1.8	
Redesign Subsequent to Protoflight	<u>0.3</u>	
Total Nonrecurring Effort EU		6.0

Unit Recurring Effort:

Spares	1.0	
Flight Units (Determined from launch schedule)	<u>6.0</u>	
Total Unit Recurring Effort EU		<u>7.0</u>

Total Equivalent Units 13.0

Based on the procedures described in Reference 11, the value of the EU for design and development with inheritance is determined to be 2.8 as shown in Table 8-3, and the total number of EUs with inheritance is determined to be 12.8.

Then using the CER expression to compute total cost, the unit cost is obtained by dividing the total cost determined from the CER by the number of EUs. The RDT&E cost is determined by multiplying the unit cost by the number of EUs which represent the nonrecurring effort. Using the number of EUs with inheritance, the following unit and RDT&E cost in 1974 dollars are

$$\text{Total Cost} = 0.4003 \times (3,650 \times 0.6158) \times (12.8 \times 0.9684) = \$738.4\text{M}$$

$$\text{Unit Cost} = \text{Total Cost} / \text{EU} = \$738.4 / 12.8 = \$57.7\text{M}$$

$$\text{RDT\&E Cost} = \text{Unit Cost} \times \text{EU (NR)} = 57.7 \times 5.8 = \$334.6\text{M}$$

This value of the RDT&E does not include the cost of launching the protoflight spacecraft, but does include the cost of developing and fabricating the required auxiliary ground and bench test equipment.

Table 8-3. Initial Design, Development, and Inheritance

Subsystem	Design Inheritance Satellite	% Inheritance	Subsystem % Cost Driver	Weighted Inheritance %	Fabrication		
					Thermal/Mechanical Test Unit EU	Engineer Unit EU	Redesign EU
Structure & Thermal	None	0 (1)	12	0	0.2		0.05
Electrical	None	0 (1)	20	0		0.2	0.05
Tracking & Command	ATS-F	50%	8	4.0		0.05	0.05
Stability & Control	ATS-F	10% (2)	15	1.5		0.05	0.05
Communication Antenna	ATS-F	5%	45	2.25		0.4	0.1
Transponder	None						
Total			100 -	7.75			
4.0 = 2.8 + 0.2 + 0.7 + 0.3			= 0.9225 x 3.0 = 2.8		0.2	0.7	0.3

NR effort: Design & Development 4.0
 Protoflight 1.8
 UR effort: Spare 1.0
 Six Flight Units 6.0 (Five successful, one launch failure)
 Total EU with inheritance 12.8

Notes: (1) Due to High Power
 (2) Due to Size

Frequently of interest are the spacecraft component tests. The cost estimating technique used to determine this component cost is presented in Appendix K. As stated in Paragraph 8.2, the satellites are assumed to be launched by the space shuttle. The expected launch costs are presented in Appendix L.

8.4.5 Terrestrial Telecommunications Network Costs

A basic communication implementation for the baseline terrestrial system is the leasing of telecommunication circuits. The basic charges for these leased services are listed and described here.

The cost for a single subscriber for voice circuits is the sum of the circuit mileage and the switch connection charge plus the local loop service charge. Circuit mileages are determined from a vertical and horizontal coordinate system corresponding to FCC Tariff No. 264. Essentially, these calculations are the same as airline mileages between two locations. Circuits are individually derived from TELPAK cross sections. TELPAK is procured from the telephone companies under Tariff No. 260 by the General Services Administration (GSA) and is allocated and administered by them. Because TELPAK sections do not always provide for direct connections between two locations, GSA adds an "overhead" factor called the detour ratios. The FY74 TELPAK charges for a single voice grade circuit was 42 cents per mile per month and the detour ratio was 1.2362. Therefore, the monthly cost of a 100-mile circuit was $\$0.42 \times 100 \text{ miles} \times 1.2362 = \51.92 for circuit mileage only. Every subscriber access line in CONUS that uses TELPAK is charged a fixed TELPAK connection charge per month for each end of the line. The charge is fixed and is \$40 for each end or a total of \$80 per month for each CONUS access line using TELPAK. To determine the TELPAK termination charge, the user must multiply each CONUS access line using TELPAK by \$80 per month. In addition to the line and connection charges, there is a \$15 per month local loop service charge.

8.4.6 Direct Estimation

Cost Estimating Relationships (CERs) exemplified by the CER used to develop the cost estimate for the satellite are derived from historical data and are appropriate for projecting the cost of similar type items which differ only in the value of the parameters used in the CER, such as size, power, capacity, weight, range, et cetera. When there is a lack of historical data from which to derive valid CERs, it is necessary to develop cost estimates by direct estimation techniques, such as estimating by comparison and detailed estimating.

Direct cost estimates for launch services have been furnished by NASA and the telecommunication charges are available from tariff schedules. Cost estimates are required for the ground system terminals and the data collection system, the broadcast receivers of the public information and warning system, and the broadcasting facilities of the baseline terrestrial DWS. The unit cost estimates for these

subcomponent systems will be developed by direct estimation techniques by which the gross costs and engineering inputs are based on preliminary engineering calculations. There are two methods for directly estimating the cost and the applicability of each method, depending on the development stage of the units to be tested. First, there is the direct comparison by which the major system equipment can be directly compared to similar items which have recently been procured or are in production. The unit cost of these "off-the-shelf" items then forms a basis for a comparative cost estimate of the similar equipment in the proposed alternatives. The second method of detailed estimation derived a cost estimate for the component parts shown by the engineering sketches and diagrams developed during the course of this feasibility study.

In developing cost estimates for many types of items, in particular electronic items, the number of units produced, or the "size of buy" is an essential item. Generally, the larger the "size of buy", the less the unit cost. This reduction in the per unit cost is due to an increase in worker efficiency resulting from the learning process and the procedure for determining the amount of reduction is determined by the "learning curve" which is explained in Appendix M.

The direct cost estimating procedures previously outlined estimate the unit cost, which is only a part of the total system cost. This unit cost generally addresses only the major system equipment and does not include the cost of the secondary items or support facilities which may be part of the unit recurring cost. Further, these methods do not generate an estimate of the annual recurring cost for operations and maintenance or the nonrecurring cost for research and development. The usual procedure to develop the gross parametric estimate of these costs is to use factors which represent a percentage of the unit cost.

The application of the costing techniques of comparison and detailed estimation for the different components of the DWS is presented in Appendix M, which also contains the formulations of learning curves and the cost factors (unit recurring and annual recurring) used in the cost estimations.

8.4.7 Personnel Costs

In the absence of a specific grade structure, a representative pay rate must be used in costing civilian personnel referred to as general schedule (GS) employees. The basic pay rates were adjusted to include contributions for employee benefits and pay differentials. The benefits include health insurance, retirement, FICA, and Federal Employment Compensation Action. The pay differentials include overtime, night, and Sunday/holiday differential. No adjustment is made for sick and annual leave, holiday, and other paid leave accruals since the number of personnel required is based on the use of five shifts to provide 24 hours per day, 7 days per week operation. The use of the five shifts compensates for nonproductive leave and holidays.

The only personnel who will be costed in this comparative analysis will be those required to man, on a full-time basis, equipment unique to one of the alternatives. Personnel who operate items such as weather office terminals in addition to their other duties will not be charged against the system. Personnel costed will be Electronic Technicians/Communication Management personnel and the median grade for this occupational category is GS-11 (Reference 12). The median step for the GS-11 employees is Step 5 (Reference 13). The median grade for Department of Commerce employees is GS-10 (Reference 13). Therefore, the basic pay rate for a GS-11, Step, Step 5 employee is selected as the representative pay rate for this estimate in the absence of a specific grade structure.

Base Pay GS-11/5	16,627 pa (FY74\$)
Differential: overtime 3%, night 4%, Sunday/holiday 3%	\$1,663
Benefits: Retirement, Health, Insurance 8.6%	<u>1,430</u>
	19,720
Department Overhead (1972\$) \$3,190 (PCS, Supplies, Rent, Printing, Equip) Adjusted to 1974\$ increase 10.2% (Based on Federal Pay increases as overhead is more pay related.	3,515
	<u>\$ 23,235</u>

Therefore, the burdened cost per man-year for Electronic Technicians/Communication Management personnel will be estimated at \$23,200 per year. Each operating position which requires manning for 24 hours per day, 7 days per week will be estimated at \$116,000 per year.

8.5 COST ESTIMATES

This paragraph contains the estimated total life-cycle costs for each of the baseline systems. The cost estimates have been made for each of the subcomponent systems in each cost category except for the public information and warning system where the subcomponent system costs have been consolidated. The "salvage" value of the baseline satellite system represents the unexpended useful life of the satellites in orbit and the spares on hand. The use of the salvage value in this manner makes a more valid cost comparison between the baseline systems since the DWS will continue in use after the 10-year period and the remaining useful life of the satellites represents a real asset.

8.5.1 Baseline Satellite DWS

8.5.1.1 Total System

The estimated total life cycle costs for the baseline satellite DWS is shown in Table 8-4. These costs are shown for each of the cost categories in millions of FY 74 dollars. The detailed breakdowns of each of these cost categories are contained in the following paragraphs.

8.5.1.2 Satellite System

8.5.1.2.1 Baseline Spacecraft

Baseline Spacecraft: 3650 kilograms (8048 pounds) and 12.8 equivalent units.

Nonrecurring Cost: Based on the satellite weight and the number of equivalent units the estimated R&D cost derived by the CER described in Paragraph 8.4.4 is \$334.6 million.

Unit Recurring Cost: Based on the launch schedule derived in Paragraph 7.10, six successful launches (including protoflight) are required to maintain the desired reliability of the system. A probability of 0.85 is assumed for a successful launch. Therefore, seven satellites will be required for launch (including protoflight). In addition, there is a requirement for an on-hand spare. In the event of launch failure, the on-hand spare would be launched and another spare would be procured immediately. The cost of the protoflight unit is included in the nonrecurring cost. In summary, the unit recurring costs for satellite procurement are for five satellites launched successfully, one satellite expended as a launch failure, and an on-hand spare, a total of seven. These seven spacecraft, in addition to the protoflight unit, must be procured over the 10-year operating period at a unit cost of \$57.7 million each, or a total of \$403.9 million.

Annual Recurring Cost: None.

Salvage Value: The salvage value at the end of the 10-year period are based on prorating the remaining reliability of the satellite over the 6-year useful satellite life. The spare which has not been launched has all of its useful life remaining and has a factor of 1. From the launch schedule it is determined that there are two satellites in orbit at the end of the 10-year period; one has been in orbit for 1.5 years, while the other for 3.5 years. The factor for the satellite in orbit for 1.5 years is the ratio

$$\frac{R(1.5) - R(6.0)}{R(0) - R(6.0)} = 0.8237$$

Table 8-4. Baseline Satellite DWS, Estimated Total Life Cycle Costs

System/Subsystem	Nonrecurring Cost	Unit Recurring Cost	Annual Recurring Cost	Salvage Value	Total Life-Cycle Cost
Satellite System	347.9	483.7	13.3	145.2	699.7
Spacecraft	(321.3)	(403.9)	None	(128.8)	(596.4)
Launch Service	(13.3)	79.8	None	(16.4)	(76.7)
AGE	(13.3)	None	(13.3)	None	(26.6)
Ground Terminal	7.9	31.7	33.8	None	73.4
WSO Terminal	(2.5)	(31.7)	(18.4)	None	(52.6)
CCS	(5.4)	None	(15.4)	None	(20.8)
Public Information * and Warning System	2.5	0.1	0.1	None	2.7
Collection System	2.9	628.4	208.0	None	839.3
DCP	(0.4)	(125.0)	(47.2)	None	(172.6)
Spotter	(2.5)	(503.4)	(160.8)	None	(666.7)
Baseline System Total	361.2	1143.9	255.2	145.2	1615.1

NOTE: Costs are shown in millions of FY 74 dollars.

*Cost of home warning receivers to the public not included. Retail cost range of home warning receivers is estimated at \$52 to \$97.

where $R(1.5)$ is the reliability of the satellite at the end of 1.5 years and $R(0) = 1$. Similarly, the factor for the satellite which has been in orbit for 3.5 years is 0.4098. The sum of these three factors is 2.2335 which is multiplied by the unit cost to obtain \$128.8 million as the value of satellite "life" on hand at the end of the 10-year period.

8.5.1.2.2 Launch Costs

Based on the spacecraft size, and using the data in Appendix L, the cost of the OOS will be \$2.5 million and the cost of the space shuttle will be \$10.8 million for a total launch cost of \$13.3 million.

Nonrecurring Cost: Launch of protoflight is estimated at \$13.3 million.

Unit Recurring: The expected number of launches during the 10-year period is six (excluding the protoflight) and the estimated cost is \$79.8 million.

Salvage Value: The prorata share of the launch costs for the unexpended spacecraft life is estimated to be $(0.8237 + 0.4098)$ times 13.3, or \$16.4 million.

8.5.1.2.3 Auxiliary Ground Equipment (AGE)

Nonrecurring Cost: The development and fabrication of the auxiliary ground equipment is included in the spacecraft R&D cost derived by the CER (Reference 11). The value is estimated as 30 percent of the spacecraft platform cost. The sum of the AGE cost and spacecraft cost is considered to be the unit cost derived by the CER so that the AGE cost is 23 percent of the unit cost.

Unit Recurring Cost: It is anticipated that only one spacecraft at a time will be fabricated and it is therefore unnecessary to procure additional sets of AGE.

Annual Recurring Cost: The annual recurring cost for the operation and maintenance of the AGE is estimated at 10 percent of the acquisition cost, or \$1.3 million per year.

8.5.1.3 Ground Terminal System

8.5.1.3.1 Weather Service Office (WSO) Terminal

Nonrecurring Cost: Cost for design and development of the WSO satellite ground terminal is estimated to be \$2.5 million. This cost will include the fabrication of a prototype terminal.

Unit Recurring Cost: The total estimated cost for the component parts for each terminal is \$36.8 thousand in quantities of 300. Assuming that the parts represent 55 percent of the selling cost, the factory unit cost is estimated to be \$66.9 thousand. Estimates for secondary items are as follows (in thousands of dollars):

Installation/Acceptance Test	20%	\$ 13.4
Initial Spares & Repair Parts	10%	13.4
Test/Maintenance Equipment	15%	10.0
Transportation	3%	<u>2.0</u>
Total Secondary Items		\$ 38.8
Total Unit Procurement		\$105.7

And for the total of 300 units, the total estimated unit cost is \$31.7 million.

Annual Recurring Cost: The cost of consumables and supplies is estimated at 10 percent of the unit cost of the terminal equipment and the test/maintenance equipment; or \$7.7 thousand dollars per terminal per year or a total cost for 300 terminals of \$2.3 million per year after all units have been procured. During the initial period of acquisition (5 years) there will be approximately one-fifth the number of WSO terminals installed each year, so that the total number operated each year will increase by about one-fifth of the total number. Therefore, the total cost for the 10-year period is only 80 percent of what the cost would have been if all of the units had been installed the first year and operated for the entire 10 years. The total estimated annual recurring cost is \$18.4 million.

8.5.1.3.2 Central Control Station (CCS)

Nonrecurring Cost. Cost of the design and development of those CCS components common to the WSO terminal are included in the R&D cost for the WSO satellite terminals. However, the CCS will require additional R&D effort in addition to software development; these costs are estimated to be \$1.0 million and \$0.6 million, respectively. Since there is only one central control station, the prototype unit will become the operational CCS and the total procurement cost for the CCS and the TT&C facilities which will be collocated are considered to be nonrecurring cost.

The total cost breakdown in millions of dollars is as follows:

Additional R&D	\$1.0
Software	0.6
Component Cost (\$.33M which is 55 percent of factory cost)	0.3
Factory Cost	0.6

Computer	0.2	
TT&C Stations	3.0	(Includes two TT&C stations and physical plant which is necessary to support the CCS complex.)
<hr/>		
TOTAL	\$5.4 million	

Annual Recurring Cost: This installation will require approximately 10 positions to man on a 24 hour per day, 7 day per week basis. Five man years is equivalent to one position-year.

Operations Personnel	\$1.16 million per year
Operations and Maintenance (10 percent of nonrecurring cost less additional R&D and Software)	<u>.38</u>
Total Annual Estimated Cost	\$1.54 million per year.

8.5.1.4 Public Information and Warning System

8.5.1.4.1 Home Receivers

The rationale for estimating the cost for the three different types of home broadcast receivers is shown in Table 8-5. The estimated retail cost range, as well as component and factory costs, shown for the three different types of receivers are shown in Figures 8-1, 8-2, and 8-3 over a large span of quantity values using the learning curve technique with a learning factor of 0.9. The retail cost range is determined by considering both the retail and wholesale percent markups to determine the markup factor (Reference 14). The wholesale and retail costs are computed as follows:

$$\begin{aligned}
 W &= C/(1-w) \\
 R &= W/(1-r) \\
 \text{Markup Factor} &= R/C = 1/(1-w)(1-r)
 \end{aligned}$$

where

C = Factory Price

W = Wholesale Price

R = Retail Price

w = Wholesale percent markup

r = Retail percent markup.

Table 8-5. Home Broadcast Receiver Cost Estimates

Cost Elements	Image Reject (10 channels)	Non-Image Reject (10 channels)	Reduced Capacity (2 channels)
Component Cost (dollars) for Quantities of: <div> <div>(55% of</div> <div>1</div> <div>Factory Cost)</div> <div>5000</div> <div>10⁵</div> <div>10⁶</div> </div>	<div>140.</div> <div>38.36</div> <div>24.33</div> <div>17.14</div>	<div>114.</div> <div>31.24</div> <div>19.81</div> <div>13.96</div>	<div>79.</div> <div>21.65</div> <div>13.73</div> <div>9.67</div>
Learning Factor	0.9	0.9	0.9
Integration/Assembly/Test Parts and Labor 25%	7.79	6.35	4.40
Management, Profit and Overhead 20%	6.23	5.08	3.52
Factory Cost (Based on Quantity of 10⁶)	31.17	25.38	17.60
Retail Price Range (Quantity of 10⁶) <div> <div>Min. Markup Factor</div> <div>1.667</div> </div> <div> <div>Max. Markup Factor</div> <div>3.125</div> </div>	<div>\$51.95</div> <div>\$97.41</div>	<div>\$42.31</div> <div>\$79.32</div>	<div>\$29.32</div> <div>\$54.97</div>

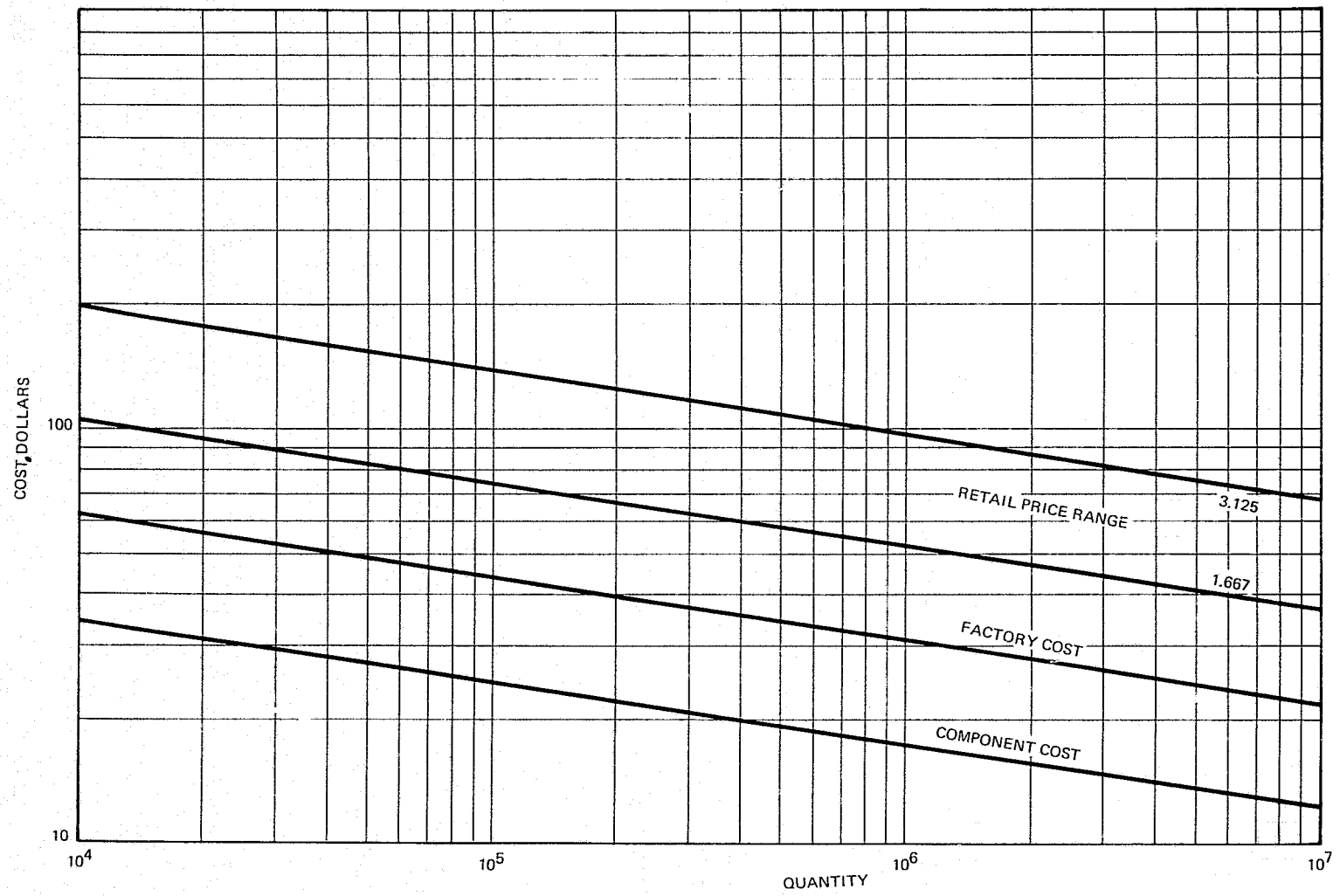


Figure 8-1. Home Broadcast Cost Estimates, Image Reject

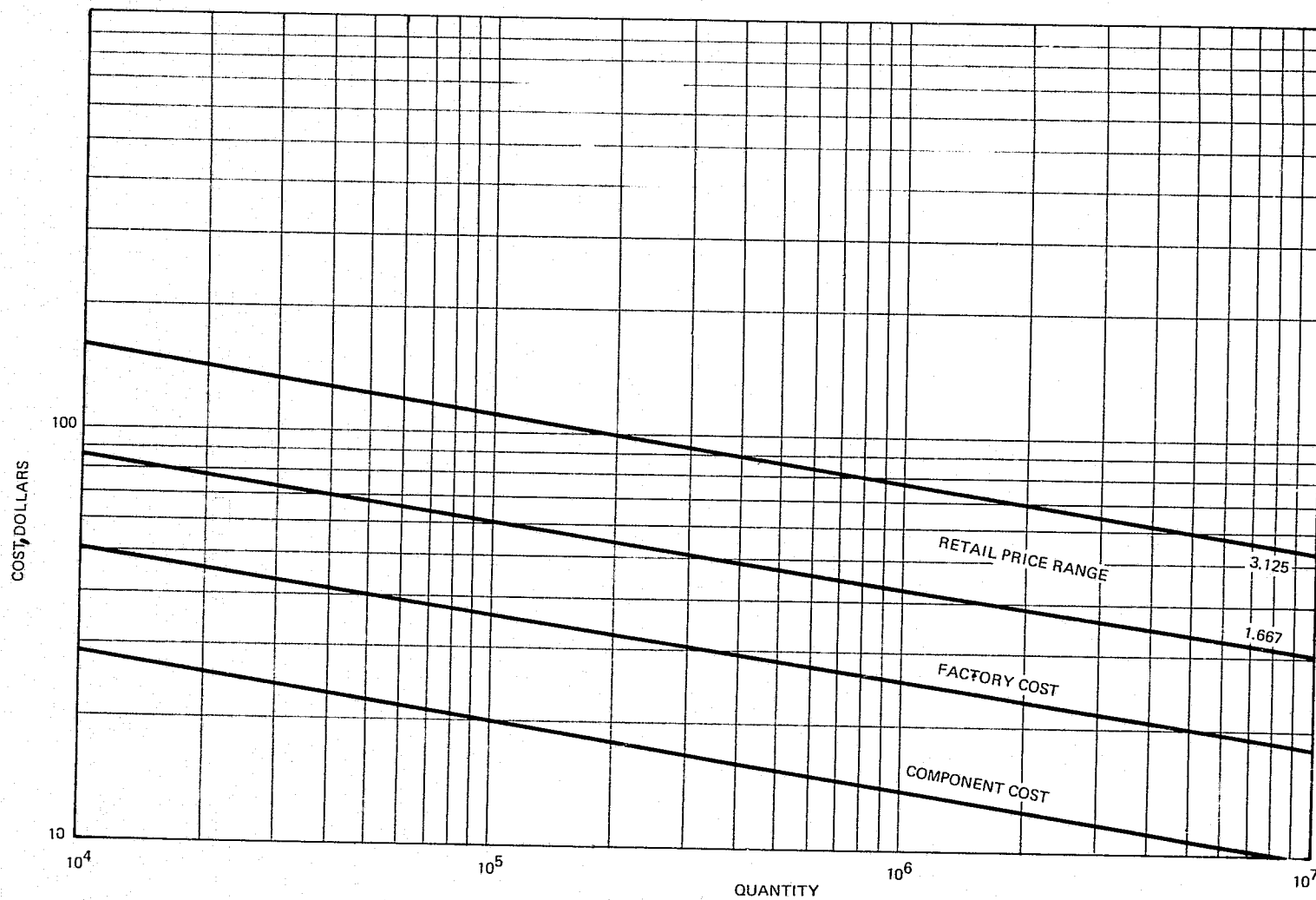


Figure 8-2. Home Broadcast Receiver Cost Estimates, Nonimage Reject

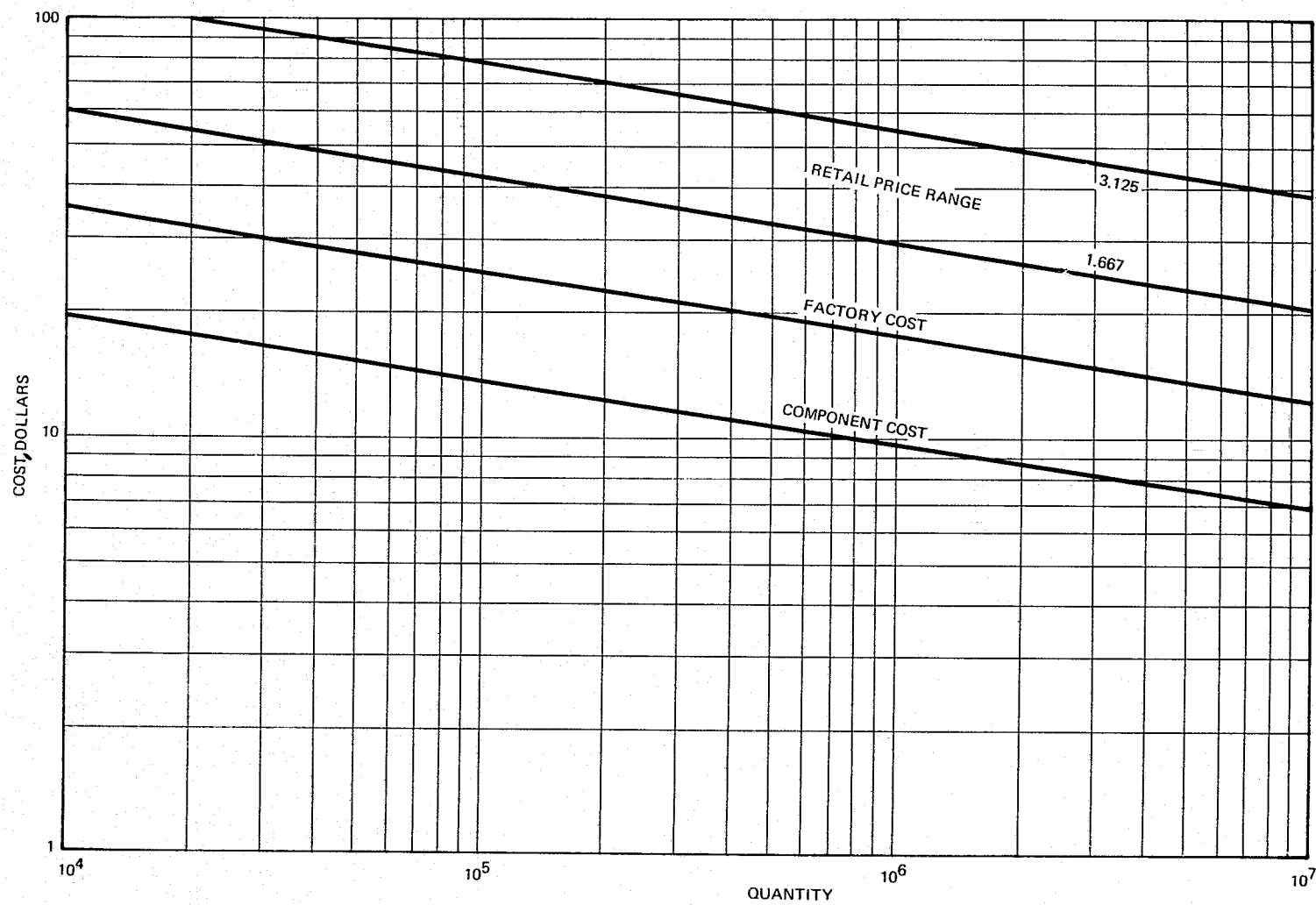


Figure 8-3. Home Broadcast Receiver Cost Estimates, Reduced Capacity

The markup factors for a range of merchandising outlets are:

	Percent		Markup
	<u>w</u>	<u>r</u>	<u>Factor</u>
Discount Stores	-	40%	1.667
Department Stores	20%	30%	1.786
Radio/TV Stores	20%	40%	2.083
Camera Stores	20%	60%	3.125

8.5.1.4.2 Local Community and Official Receivers

Since the design of the home broadcast receivers and the local community and official receivers is similar, it is anticipated that the estimated cost will also be similar.

The local community and official broadcast receivers are the image reject type with two helix antennas per installation. It is anticipated that the Federal Government will pay 50 percent of the procurement and operation and maintenance costs for the estimated 3000 local community receivers under the provisions of PL 91-606 which authorizes matching funds for the development and maintenance of State Disaster Plans.

Nonrecurring Cost: It is estimated that \$2.5 million will be required in research and development effort to design, develop, fabricate, and test the broadcast receivers. This estimate includes the development of the home broadcast receiver which is the same as the broadcast receivers to be used by the local community officials and federal agencies.

Unit Recurring Cost:

Major System Equipment

Component Costs	\$17.14	Quantity of 10 ⁶
Antenna Cost	<u>4.12</u>	Quantity of 3500
Total Component Cost	\$21.26	

Integration/Assembly/Test

Parts and Labor 25%	\$ 9.66
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Management Profit and

Overhead 20%	<u>\$ 7.73</u>
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Factory Cost	\$38.65
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Secondary Items

Installation/Acceptance 20%	\$ 7.73
Initial Spares & Repair Parts 20%	\$ 7.73
Test/Maintenance Equipment 10%	\$ 3.86
Transportation 3%	<u>\$ 1.16</u>
Total Unit Procurement Cost	\$59.13
Local Community: $\frac{1}{2} \times 3,000 \times 60 =$	\$ 90,000
Official: 500×60	<u>30,000</u>
Total Procurement	\$120,000

Annual Recurring Cost: Units are user operated and it is estimated that maintenance costs will be approximately 5 percent per year of the major system equipment cost.

Annual Recurring Cost	\$4,000
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The magnitude of the procurement is such that these units could easily be procured during the first year and operated for the entire 10-year period for a total of approximately \$40,000.

8.5.1.5 Collection System

8.5.1.5.1 Data Collection Platform (DCP)

The transceivers for the DCP are similar to those currently being implemented in the GOES program. Also, the transceivers for the reconnaissance aircraft are similar to the DCP transceiver and, due to the extremely limited number required, the cost of the transceivers for the aircraft are included in the cost for the DCP. The stated requirement is for 20,000 of these units. It is estimated that two-thirds will be of the interrogated type and one-third will be the self-timed type. Due to the large number of units that are required, it is anticipated that the procurement will be over a 5-year period and that each year's procurement will represent a separate buy. The learning factor for these units is estimated at $L = 0.88$ (Reference 15). Further, it is estimated that these transceivers will have a life of 5 years and the yearly procurement will be continued for 10 years.

Nonrecurring Cost: Most of the development cost can be considered as sunk due to the development for the current GOES program. It is estimated that approximately \$400,000 will be required to adapt the design for the GOES program to the DWS satellite.

Unit Recurring Cost:

Major System Equipment

Estimated Factory Cost (1972 Dollars)	\$3,082	\$2,330
Adjust 1972 Dollars to FY 74 Dollars (19.6%)	3,686	2,787
Unit Cost - 2667 1333	2,012	1,729

Secondary Items

Field Installation 20%	402	346
Initial Spares/Repair Parts 20%	402	346
Test/Maintenance Equipment 15%	302	259
Transportation 3%	60	52
	\$3,178	\$2,732
Plus Deployment to Site	100	100
	\$3,278	\$2,832

Times Quantity \$8.7 million/yr. \$3.8 million/yr.

Total Procurement per year \$12.5 million/year or \$125 million for the 10-year period.

Annual Recurring Cost: It is estimated that each DCP will have to be visited twice each year for maintenance of the transceiver (Reference 15). The cost for parts is estimated at 5 percent per year and the cost of a trip to the remote site is estimated at approximately \$100, the same as for deployment of the unit to the site. Therefore, on an annual basis, when there are 20,000 DCP in place, the cost is:

Trips $2 \times 100 \times 20,000$	\$4.0 million
Parts $2/3 \times 20,000 \times .05 \times 2012$	1.3
$1/3 \times 20,000 \times .05 \times 1729$.6
	\$5.9 million

During the period of initial procurement there will be only one-fifth of the total number installed each year, so that the total cost for the 10-year period is only 80 percent of what the cost would have been had all units been installed and operated for the first year. Therefore the total estimated annual recurring cost is \$47.2 million.

8.5.1.5.2 Spotter Terminals

The spotter terminal stated requirement is for 100,000 units. Again, it is anticipated that this procurement will be spread over a period of 5 years and that there will be two buys of 10,000 each year. The learning curve factor for this terminal is estimated at 0.90. The cost of installing the terminal and antenna in a vehicle is estimated to be \$200.

Nonrecurring Cost: It is estimated that \$2.5 million will be required for the design, development, fabrication, and test of the spotter terminals.

Unit Recurring Cost:

Major System Equipment

Estimated Cost of Component		
Parts	55%	2,462 Quantity of 5000
Integration/Assembly/Test		
Parts and Labor	25%	1,119
Management, Profit, and		
Overhead	20%	895
Factory Cost		4,476 Quantity of 5000
		4,028 Quantity of 10,000

Secondary Items

Installation		200
Initial Spares/Repair Parts	7%	282
Test/Maintenance Equipment	10%	403
Transportation	3%	<u>121</u>
		\$5,034

The total estimated cost for the procurement of 100,000 units is \$503.4 million.

Annual Recurring Cost: The units will be user operated and there are no personnel costs incurred in the operation. It is estimated that the maintenance cost of the spotter terminals will be 5 percent of the unit cost; $.05 \times \$4,028 \times 100,000 = \20.1 million per year, a total of \$160.8 million for the 10-year period. The estimated cost for the 10-year period is 80 percent due to the initial procurement spread over a 5-year period.

8.5.2 Baseline Terrestrial DWS

8.5.2.1 Total System

The estimated total life cycle costs for the baseline terrestrial DWS is shown in Table 8-6. These costs are shown for each of the cost categories in millions of FY 74 dollars.

8.5.2.2 Terrestrial Network

8.5.2.2.1 Telecommunications

The estimated cost for the telecommunications network for the terrestrial system will be based on dedicated, dual lines between the WSOs and 500 spotter control headquarters, 25 news media, 500 federal agency officials, and 3000 local community officials. It is estimated that the average straight line distances between each type of agency and the two nearest WSOs to which it will be connected are:

WSO to Spotter Control Headquarters	35 miles
WSO to News Media	175 miles
WSO to Federal Agency	30 miles
WSO to Local Community Official	50 miles
WSO to WSO - 123,430 miles, dual lines, for 353 offices, derived from office grid coordinates.	

The telecommunications circuits are leased circuits and there will be no non-recurring costs or unit recurring costs or unit recurring costs. The estimated annual recurring costs are shown in Table 8-7.

8.5.2.2.2 Broadcasting Facilities

The broadcasting facilities of the terrestrial DWS are similar to the current NWS VHF-FM Weather Transmission System and the estimated costs for this system were derived by a direct comparison with the equipment of that system. Based on an average effective broadcasting radius of 65 kilometers, approximately 750 transmitters would be required to cover the 50 states plus the Caribbean, including land and water

Table 8-6. Baseline Terrestrial DWS, Estimated Total Life-Cycle Costs*

System/Subsystem	Nonrecurring Cost	Total Unit Recurring Cost	Total Annual Recurring Cost	Total Life Cycle Cost
Terrestrial Network	None	28.4	490.5	518.9
Telecommunications	None	None	(144.0)	(144.0)
Broadcasting Facilities	None	(28.4)	(346.5)	(374.9)
Public Information and Warning System	2.5	0.1	0.1	2.7
Collection System	None	332.4	151.0	483.4
DCP	Sunk	(125.0)	(61.2)	(186.2)
Spotter	None	(207.4)	(89.8)	(297.2)
Baseline System Total	2.5	360.9	641.6	1005.0

NOTE: Costs are shown in millions of FY 74 dollars.

*Cost to the public of home warning receivers not included. Retail cost range of home warning receivers for the baseline terrestrial system is estimated at \$30 to \$55.

Table 8-7. Terrestrial Telecommunications Estimated Annual Recurring Costs

<u>SPOTTER CONTROL HEADQUARTERS</u>				
Mileage	$500 \times 35 \times \$0.5192 \times 2$	=		18,172
TELPAK Connections	$500 \times 40 \times 2 \times 2$	=		80,000
Local Loop Service	$500 \times 15 \times 2 \times 2$	=		<u>15,000</u>
				113,172
<u>NEWS MEDIA</u>				
Mileage	$25 \times 175 \times \$0.5192 \times 2$	=		4,543
TELPAK Connections	$25 \times 40 \times 2 \times 2$	=		4,000
Local Loop Service	$25 \times 15 \times 2 \times 2$	=		<u>750</u>
				9,293
<u>NATIONAL ORGANIZATIONS</u>				
Mileage	$500 \times 30 \times \$0.5192 \times 2$	=		15,576
TELPAK Connections	$500 \times 40 \times 2 \times 2$	=		80,000
Local Loop Service	$500 \times 15 \times 2 \times 2$	=		<u>15,000</u>
				110,576
<u>LOCAL COMMUNITY OFFICIALS</u>				
Mileage	$3000 \times 50 \times \$0.5192 \times 2$	=		155,760
TELPAK Connections	$3000 \times 40 \times 2 \times 2$	=		480,000
Local Loop Service	$3000 \times 15 \times 2 \times 2$	=		<u>90,000</u>
				725,760

Table 8-7. Terrestrial Telecommunications Estimated Annual Recurring Costs (Cont'd.)

<u>WSO to WSO</u>			
Mileage	123,430 x \$0.5192	=	64,085
TELPAC Connections	353 x 40 x 2 x 2	=	56,480
Local Loop Service	353 x 15 x 2	=	10,500
Terminal Charge	250 x 353	=	82,250
Hawaii to CONUS Circuit @	\$5,200 x 2	=	10,400
Alaska to CONUS Circuit @	\$3,000 x 2		6,000
			<u>235,805</u>
Total Estimated Monthly Cost		\$1.20 million	
Total Estimated Cost for 10 year period		\$144.0 million	

by the hexagonal grid. With an estimated 300 WSOs authorized to issue warnings, there will be an average of 2.5 transmitters to each WSO. The straight line distance between transmitters is approximately 70 miles and for each WSO there is approximately 1.5×70 or 105 miles which must be connected with dual-homed, dedicated circuits. High quality emergency standby power will be required at each transmitter site with the capability to provide power over an extended period of time in the event there is a failure in the commercial power sources. There is no research and development effort anticipated since this equipment has been developed and is currently in use.

Unit Recurring Cost: The costs for the major systems equipment are based on available current data for the 1kW VHF-FM transmitter in FY74 dollars. It is anticipated that these units will be housed in existing structures wherever feasible and that antennas will be mounted on existing towers or on top of buildings. Therefore, the cost of support facilities such as land, site preparation, buildings, fencing, roads, antenna towers/foundations, etc., are not included in the estimated costs. Cost estimates such as these can only be made when transmitter sites have been selected and designed.

Major System Equipment

Control/Information Console	\$5, 500
Transmitter with interface	5, 400
Antenna, 1/2 wavelength, strengthened for 125 knot wind	1, 000
Receiver Options: Voice Monitor Alarm/Tone Alert	300
Interface Equipment	1, 000
Operational accessories	750
Electrical Power, 30 kW Standby Unit Diesel Driven in Dummy Load, Auto Transfer Panel and Switch Gear	<u>20, 700</u>
Major System Equipment Total	\$34, 650

Secondary Items

Installation/Acceptance Tests 5%	1, 732
Initial Spares Repair Parts Direct Estimate	500
Transportation 3%	1, 039
Total Procurement per site	37, 921
times 2.5 for procurement per WSO	94, 802
Total Estimated Cost for 300 WSOs	\$28.44 million

Annual Recurring Cost

Operations (cost per average WSO)	
Consumable Supplies 10% of major system equipment total	\$8,662
Util, Heat Bldg Maint. \$500/site/mo.	15,000
Personnel, one communication technician per WSO	116,000
Communications (cost per average WSO)	
Mileage 105 x 2 x \$0.5192	109
TELEPAK Connections 2 x 40 x 1.5 x 2	240
Local Loop Source 2 x 15 x 1.5 x	<u>45</u>
Estimated Average Monthly Cost	\$ 394
Estimated Average Annual Cost	4,728
Total Annual Recurring Cost per WSO	\$144,390

Total Annual Recurring Cost for 300 WSOs based on 80 percent of 10 year operating cost due to phase in of facilities over 5-year period is \$346.5 million.

8.5.2.3 Public Information and Warning System

8.5.2.3.1 Home Receivers

The home broadcast receivers for this system will be the reduced capacity (2-channel) receivers, the costs of which were derived in Table 8-5. The estimated component cost for quantities of one million is \$9.67, the estimated factory cost is \$17.60, and the estimated retail price range is from about \$30 to \$55 as shown in Figure 8-3.

8.5.2.3.2 Local Community and Official Receivers

In the baseline terrestrial system the local community and official receivers are the reduced capacity type with two channels and with an exterior antenna per installation. Again, it is anticipated that the Federal Government will pay for 50 percent of the procurement and operations costs for the estimated 3000 local community receivers under the provisions of PL 91-606. In addition, warning receivers will be procured for the spotter control headquarters.

Nonrecurring Cost: It is estimated that \$2.5 million will be required for the design development, fabrication, and testing of the DWS. This estimate also includes the development of the home FM broadcast receiver which is similar to the broadcast receiver to be used by the local community officials and the federal agencies.

Unit Recurring Cost:

Major System Equipment

Component Cost	\$9.67	(10 ⁶)
Antenna Cost	<u>2.06</u>	(3500)
Total Component Cost	\$11.73	

Integration/Assembly/Test

Parts and Labor 25%	5.33
Management, profit and overhead, 20%	4.27
Factory Cost	21.33

Secondary Items

Installation/Acceptance 20%	4.27
Initial Spares/Repair Parts 20%	4.27
Test/Maintenance Equipment 10%	2.13
Transportation 3%	.64
Total Procurement Cost	32.64

Local Community $1/2 \times 3000 \times 33 = 49,500$

Official $500 \times 33 = 16,500$

Spotter Control Headquarters $500 \times 33 = \underline{16,500}$

\$82,500

Annual Recurring Costs: Units are user-operated and it is estimated that the maintenance cost will be approximately 5 percent per year of the major system equipment cost plus test and maintenance equipment which is \$2900.

The magnitude of the procurement is such that these units could easily be procured during the first year and operated for the entire 10 year period for approximately \$29,000.

8.5.2.4 Collection System

8.5.2.4.1 Data Collection Platforms (DCP)

The estimated costs for the terrestrial system are the same as for the baseline satellite DWS except that there is no nonrecurring cost. The R&D effort for the GOES

program is considered sunk. Again, the stated requirement is for 20,000 DCP to be procured over 5 years. The cost of the transceivers for the reconnaissance aircraft is considered to be included in this estimated cost.

Nonrecurring Costs: Sunk

Unit Recurring Costs: \$125.0 million

Annual Operating Cost:

Operations:

Personnel: 60 required at two facilities to read out transmitted data and to relay data to proper WSO	\$1.4 million
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Maintenance:

Same as for baseline Satellite System	<u>\$5.9 million</u>
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Annual Recurring Cost	\$7.3 million
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During the initial period, the 80-percent factor applies only to the maintenance costs, while the personnel costs will be incurred for the entire period. Thus, the total annual costs are:

$$\begin{aligned}
 1.4 \times 10 &= 14 \\
 5.9 \times 10 \times .8 &= \underline{47.2} \\
 &\$61.2 \text{ million}
 \end{aligned}$$

8.5.2.4.2 Spotter Network

In the baseline terrestrial system, the spotters will use FM radios to communicate with the spotter control headquarters where the information will be relayed to the WSO. The personnel who man the spotter control headquarters do this in addition to other duties, may be volunteers who receive no pay, or may be paid volunteers. It is estimated that only one-fourth of the spotter control headquarters are manned by paid personnel.

Nonrecurring Costs: None

Unit Recurring Cost:

Major System Equipment

100,000 mobile unit FM transmitter/receiver @\$1,500	150.0 million
500 spotter control Hq FM transmitter/receiver @\$5,000	<u>2.5 million</u>
	152.2 million

Secondary Items

	Mobile Units	HQ Units
Installation	200	
Installation 5%		250
Initial Spares/Repair parts	150	500
10%		
Test/Maint Equipment 10%	150	500
Transportation 3%	<u>45</u>	<u>150</u>
	\$54.5 million	\$0.7 million

Total Procurement for spotter network is \$207.4 million.

Annual Recurring Cost

	Mobile Units	HQ Units
Operation: Personnel		
500 x 0.25 x 23.2		\$2.9 million
Maintenance 5% of Major		
System Equipment	<u>\$7.5 million</u>	<u>.1 million</u>
	7.5 million	3.0 million

Based on the assumption that the spotter network is acquired over a 5-year period, the total annual recurring cost is 80 percent of \$76 million plus \$29 million, or \$89.8 million.

8.6 COST SENSITIVITY ANALYSIS

The first step in the analysis will be to establish the relative cost of each of the four DWS functional requirements for each of the two baseline systems and then identify those factors which are cost drivers for each of the baseline systems. The analysis will conclude with cost estimates for some alternative systems for reduced DWS requirements in the cost sensitive areas.

8.6.1 Cost Comparisons

The baseline terrestrial system costs and the relation of these costs to the four DWS functional requirements are shown in Table 8-8. The cost elements are listed in terms of the WBS component and subcomponent systems. The same information for the baseline satellite system is shown in Table 8-9. Those elements common to both systems are the public information and warning receivers, warning receivers other than home receivers, data collection platforms, remote sensors, and the spotter equipment. For the satellite system, the spotter equipment is only

Table 8-8. Baseline Terrestrial Function
and Element Cost

FUNCTION ELEMENT	DISASTER WARNING (%)	SPOTTER REPORTS (%)	DATA COLLECTION (%)	COORDINATION (%)	TOTAL (\$ M)
WARNING NETWORK	100	0	0	0	375
TERRESTRIAL NETWORK	0	0	50	50	144
PUBLIC INFORMATION & WARNING EQUIP.*	100	0	0	0	3
DATA COLLECTION PLATFORM	0	0	100	0	186
SPOTTER EQUIPMENT	0	100	0	0	297
TOTAL	37	30	26	7	1005

* HOME RECEIVER COST NOT INCLUDED
ESTIMATED UNIT FACTORY COST: \$17.60
FOR QUANTITIES OF 1 MILLION

Table 8-9. Baseline Satellite Function
and Element Cost

FUNCTION ELEMENT	DISASTER WARNING (%)	SPOTTER REPORTS (%)	DATA COL- LECTION (%)	COORDINATION (%)	TOTAL (\$ M)
SATELLITE	90	8	1	1	700
GROUND TERMINALS	95	3	1	1	73
PUBLIC INFORMATION & WARNING EQUIP.*	100	0	0	0	3
DATA COLLECTION PLATFORM	0	0	100	0	173
SPOTTER GROUND EQUIPMENT	0	100	0	0	666
TOTAL	44	45	11	—	1615

* HOME RECEIVER COST NOT INCLUDED
ESTIMATED UNIT FACTORY COST: \$31.20
FOR QUANTITIES OF 1 MILLION

the spotter transceivers, while for the terrestrial system the spotter equipment includes not only the mobile spotter transceivers, but also the radio equipment required for the spotter control headquarters. Estimates of the percentage of element costs that contribute to the performance of the system functions are also presented in Tables 8-8 and 8-9.

For the terrestrial system, each element cost can be assigned 100 percent to a system function except for the terrestrial network which is divided evenly between the data collection and coordination functions. In terms of the total system cost, the disaster warning function contributes the greatest percentage (37 percent) followed by spotter reports, data collection, and coordination functions, in that order.

The two major element costs of the baseline satellite system are the satellite and the spotter ground equipment. For the system, the costs for the disaster warning and spotter report functions dominate. The reason the spotter reporting costs are so high is that 100,000 transceivers must be purchased and maintained for 10 years.

A comparison of the results of Tables 8-8 and 8-9 shows that the primary cost differences are for the two most costly functions: disaster warning and spotter reporting. For both functions, the baseline satellite system costs are about twice the baseline terrestrial system. Thus, from an overall cost viewpoint, the disaster warning and spotter reporting functions are of primary concern.

8.6.2 Cost Drivers

In terms of performance of the terrestrial system, the major cost drivers are the extensive coverage, complete connectivity, and fast response time. The extensive coverage, particularly for the warning function, requires a large number of transmitters, terrestrial lines to the transmitters, and consequent facility maintenance. The degree of connectivity is directly related to the mileage of terrestrial lines required; these incur an annual cost which alone is 15 percent of the total cost. Fast response time requirements dictate dedicated lines with little or no sharing which again means additional terrestrial line mileage and increased annual costs.

Figure 8-4 gives an estimate of the population coverage as a function of the number of transmitters. A precise curve can be derived only after a detailed topography survey and estimates of expected population densities in the mid 1980 are obtained. The figure also estimates the terrestrial warning cost as a function of the number of transmitters and for the continuous manning of 1.0, 0.4, and 0.2 men per transmitter facility. These estimates are based on the 10-year life-cycle cost determination in Paragraph 8.5.3.2. The baseline system of 750 transmitters

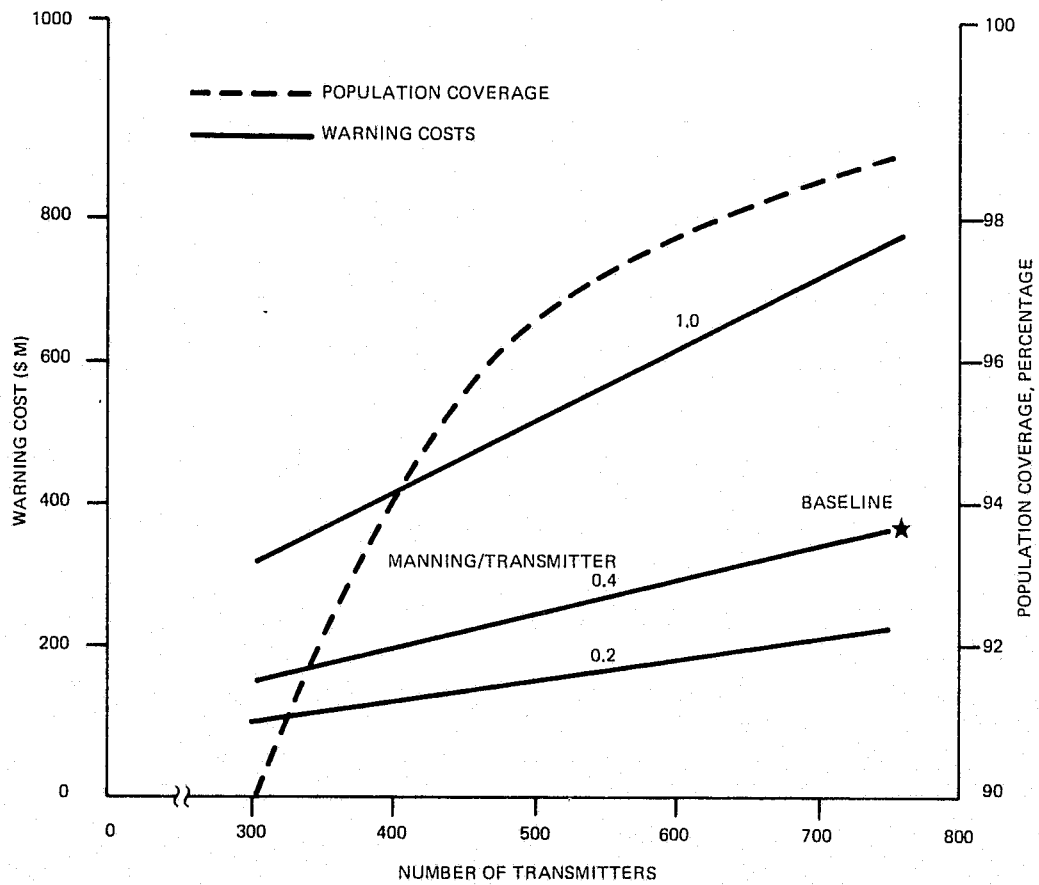


Figure 8-4. Terrestrial Average Cost

an average of 2.5 per WSO) and a manning of 0.4 (1 man per WSO) costs \$375 M. Reduction to a 95-percent population coverage reduces the number of transmitters required to approximately 420 and the cost to \$210 million. The cost dependency upon the manning is readily apparent from the results shown in Figure 8-4. It is also apparent that a detailed analysis is necessary to minimize the total warning costs by investigating the relationships among transmitter reliability, acquisition costs, and required maintenance.

The major cost drivers for the satellite system are the number of simultaneous transmissions, the use of small ground terminals, and the use of real-time voice communications. The satellite costs increase rapidly as the number of simultaneous high powered warning transmissions increase. Related to these increasing costs is the need for high powered satellite transmitters to compensate for the use of small ground terminals and for signal attenuation by buildings. Real-time voice communications requirements restrict the multiple access and modulation techniques that can be considered. FM modulation with frequency division multiple access is essentially required. However, these techniques are not efficient for a system such as the DWS which consists of a large number of low-duty cycle users.

8.6.3 Alternative System Cost Estimates

8.6.3.1 Alternative Satellite DWS

Cost estimates for the several alternative satellite DWSs are presented in Table 8-10. The case numbers refer to the case numbers in Table 7-12. These cost estimates for each alternative are broken down to the component and sub-component system level of the DWS. The physical changes indicated in the satellite system in going from one case to the next are additive.

8.6.3.1.1 Alternative Satellite Cost Estimates

The cost estimates for the satellite alternatives are based on the CER using satellite weight (kilograms) and equivalent units. Due to the weight reduction of these alternative designs the design inheritance is increased with a corresponding reduction in the number of equivalent units. Also due to the reduced weight, a kick stage on the OOS is not required and launch costs are reduced accordingly. A summary of the characteristics of the alternative satellites and the corresponding cost estimates is given in Table 8-11.

8.6.3.1.2 Ground Terminals

The WSO terminals and the CCS-TT&C facilities are the same for each of the proposed alternative satellite systems, both in number and design, and are therefore the same cost estimates as for the baseline satellite system.

Table 8-10. Alternative DWS Estimated Costs (\$M)

Case Number from Table 7-8	Satellite System	Satellite	Ground Terminals	Terrestrial Network		Public Infor- mation	Data Collection		Total
			WSO & CCS	Telecom- munications	Broad- cast		DCP	Spotter	
2	Baseline	700	73	NA	NA	3	173	667	1615
5	Reduced Channels	400	73	NA	NA	3	173	667	1316
N/A	Large Antenna	379	73	NA	NA	3	173	667	1295
6	Digital Spotter	328	73	NA	NA	3	173	445	1022
8	No Space Spotter	326	73	NA	NA	3	173	297	872
N/A	Hybrid	262	73	none	395	3	173	534	1440
	Terrestrial System								
N/A	Baseline	NA	NA	144	375	3	186	297	1005
N/A	Reduced Coverage	NA	NA	144	210	3	186	297	840

Table 8-11. Alternative Satellite Cost Estimates (\$M)

		Non-Recurring Cost	Total Unit Recurring Cost	Total Annual Recurring Cost	Salvage Value	Total Cost
Reduced Warning Channels	wt 1710 kg	161.0	326.3	8.4	95.9	399.8
Spacecraft	EU 11.1	140.6	254.3	none	81.1	313.8
Launch Services	Launch \$12M	12.0	72.0	none	14.8	69.2
AGE		8.4	none	8.4	none	16.8
Large Antenna	wt 1540 kg	151.7	310.4	7.9	90.9	379.1
Spacecraft	EU 11.1	131.8	238.4	none	76.1	294.1
Launch Services	Launch \$12M	12.0	72.0	none	14.8	69.2
AGE		7.9	none	7.9	none	15.8
Digital Spotter Link	wt 1150 kg	128.7	271.2	6.6	78.4	328.1
Spacecraft	EU 11.1	110.1	199.2	none	63.6	245.7
Launch Services	Launch \$12M	12.0	72.0	none	14.8	69.2
AGE		6.6	none	6.6	none	13.2
Terrestrial Spotter	wt 1140 kg	128.0	270.1	6.5	78.0	326.6
Spacecraft	EU 11.1	109.5	198.1	none	63.2	244.4
Launch Services	Launch \$12M	12.0	72.0	none	14.8	69.2
AGE		6.5	none	6.5	none	13.0
Hybrid	wt 750 kg	95.2	225.2	5.1	63.7	261.8
Spacecraft	EU 10.8	78.1	153.2	none	48.9	182.4
Launch Services	Launch \$12M	12.0	72.0	none	14.8	69.2
AGE		5.1	none	5.1	none	10.2

8.6.3.1.3 Public Information and Warning System

This portion of each of the alternative systems is essentially the same as for the baseline system. The reduction in the number of channels will cause a reduction in the cost of the warning receiver but this cost reduction will have an insignificant effect on the total system cost since only the official type receivers are included in the total system cost.

8.6.3.1.4 Data Collection

There will be no change in the DCP portion of the system with no resulting change in cost estimate. For the spotter equipment there will be significant change in several of the proposed alternatives. For the digital spotter link the cost of the spotter transceivers is estimated to be reduced by a factor of one-third. For the alternative in which the spotter network does not use the space segment for communication, but a terrestrial system instead, the cost is the same as for the baseline terrestrial system.

8.6.3.2 Alternative Terrestrial DWS

In this system the coverage is reduced from 99 percent to 95 percent with a corresponding reduction in the number of broadcasting VHF-FM transmitters from 750 to 420. The reduction in number of transmitters reduced the cost by \$165 M as determined from Figure 8-4.

8.6.3.3 Hybrid System

The estimated costs for the satellite of the hybrid system are shown in Table 8-11. In this system the ground terminal costs are the same as for the other satellite systems. The terrestrial link is the same as for the baseline terrestrial system except that there are no communication costs for leased lines. There are however improved receivers at each transmitter. The estimated unit procurement cost for these units is \$26.4 thousand with an annual recurring cost of \$1.9 thousand. The 10-year life cycle cost for 750 of these units is estimated at \$31.4 million.

SECTION 9 - IMPLEMENTATION PLAN

9.1 INTRODUCTION

Essential elements of the implementation plan are the designation of implementation responsibilities, the time-phased system implementation plan, and a time-phased funding plan. In the implementation of any plan which involves interagency action and coordination, it is necessary to have clearly defined responsibilities for accomplishing each element of the WBS. The time-phased system implementation plan is a schedule which identifies specific tasks and the sequence of execution that will be necessary to implement the DWS. The time-phased funding plan projects funding requirements on a year by year basis. The projection is derived by combining the element cost and the projected time for the accomplishment of the task which produces the element.

9.2 IMPLEMENTATION RESPONSIBILITIES

The general responsibilities for the implementation of the satellite DWS are shown in Figure 9-1. The overall responsibility for the DWS is vested in NOAA. NASA, however, will have the responsibility for the space segment, to include spacecraft development, providing of launch services such as the space shuttle and the orbit-to-orbit stage (OOS), as well as the necessary auxiliary ground equipment/bench test equipment for the satellite program.

The basic responsibility for the RDT&E of the satellite DWS ground components and systems integration rests with NOAA who will furnish guidance and effect the necessary coordination through appropriate agencies in the NWS and the National Environmental Satellite Service (NESS). The Engineering Division of the NWS, in coordination with the Office of Systems Engineering of NESS, will have the primary responsibility for the acquisition of the facilities and equipment for the DWS.

Maintenance responsibilities will be determined by the NWS Engineering Division with the operations under the supervision of the NWS Regional Offices and WSO/WSFO, except for the central control station with the tracking, telemetry, and command function which will be under the supervision of NESS. These responsibilities have been projected from the organizational responsibilities described in U.S. Department of Commerce, Department Organization Order 25-5B, May 7, 1973.

9.3 TIME-PHASED SYSTEM IMPLEMENTATION PLAN

9.3.1 Schedule

The implementation schedule shown in Figure 9-2 spans the period during which the system is developed, acquired, and operated for 10 years. The schedule relates

NOAA - ASSOCIATE ADMINISTRATOR FOR ENVIRONMENTAL MONITORING AND PREDICTION

	Research, Development, Test & Engineering	Acquisition - Facilities Equipment, Construction	Operation and Maintenance
Satellite DWS Program Mgmt.	NOAA - NESS in coordination with NWS	NOAA - NESS in coordination with NWS	NOAA - NWS in coordination with NESS
Satellite System Management	NASA in coordination with NOAA-NESS, Office of Systems Engineering	NASA in coordination with NOAA-NESS, Office of Systems Engineering	NASA
Spacecraft	NASA in coordination with NOAA-NESS, Office of Systems Engineering	NOAA-NESS in coordination with NASA	N/A
Launch Services	NASA	NASA	NASA
AGE/BTE	NASA	NASA	NASA
Ground Terminal Mgmt.	NOAA-NESS, Office of Systems Engineering in coordination with NWS Meteorological Operations	NOAA-NESS, Office of Systems Engineering in coordination with NWS Engineering Div.	NOAA-NWS Meteorologically Operations (Opns) and NWS Engineering Division (Maint.)
WSO Terminals	NOAA-NESS, Office of Systems Engineering in coordination with NWS Meteorological Oper.	NOAA-NESS, Office of Systems Engineering in coordination with NWS Engineering Division	NOAA-NWS Regions and WSFO/WSO
Central Control Station	NOAA-NESS in coordination with NASA	NOAA-NESS, Office of System Engineering NWS, Engineering Division	NOAA-NESS in coordination with NWS
Terrestrial Networks	NOAA- Asst Administrator for Administration	N/A	NOAA-Asst. Administrator for Administration
Telecommunications	NOAA - Office of Mgmt. and Computer Systems	N/A	NOAA - Office of Mgmt and Computer Systems
Broadcasting Facilities *	NOAA - NWS System Development Office	NOAA-NWS Engineering Divisions	NOAA-NWS WSFO/WSO (Opns) and Engineering Division/Regions (Maintenance)
Public Info. & Warning System	NOAA-NESS in coordination with NWS	NOAA-NESS in coordination with NWS	NOAA-NWS Regional Offices
Home Receivers	NOAA-NESS, Office of Systems Engineering in coordination with NWS Meteorological Oper.	NOAA- Monitored by NWS Engineering Div. in coordination with NESS, Office of Sys. Eng.	NOAA-Office of Public Affairs
Local Community Receivers	NOAA-NESS, Office of Syst. Eng. in coordination with NWS Meteorological Operations	NOAA-Monitored by NWS Eng. Div. in coordination with NESS, Office of Syst Engineering	NOAA-NWS Regional Offices
Official Receivers	NOAA-NESS, Office of Syst. Eng. in coordination with NWS Meteorological Operations	NOAA-Coordinated by NWS Eng. Div in conjunction with NESS, Office of Sys Eng.	NOAA-NWS Regional Offices
Collection System	NOAA-NESS in coordination with NWS	NOAA-NESS in coordination with NWS	NOAA-NWS in coordination with NESS
Remote Gauges	NOAA-NESS, Office of Syst Eng in coordination with NWS	NOSS-NWS, Eng Div. in coordination with NESS, Office of System Engineering	NOAA-NWS in coordination with NESS
Spotter Network	NOAA-NESS, Office of System Eng. in coordination with NWS Meteorological Operations	NOAA-NWS, Engineering Division in coordination with NESS, Office of System Eng.	NOAA-NWS Regional Offices, WSFO and WSO
Reconnaissance Acft.	NOAA-NESS, Office of System Eng. in coordination with NWS Meteorological Operations	NOAA-NWS, Engineering Div. in coordination with NESS, Office of System Engineering	NOAA-NWS National Hurricane Center

Figure 9-1. Satellite DWS Implementation Responsibilities

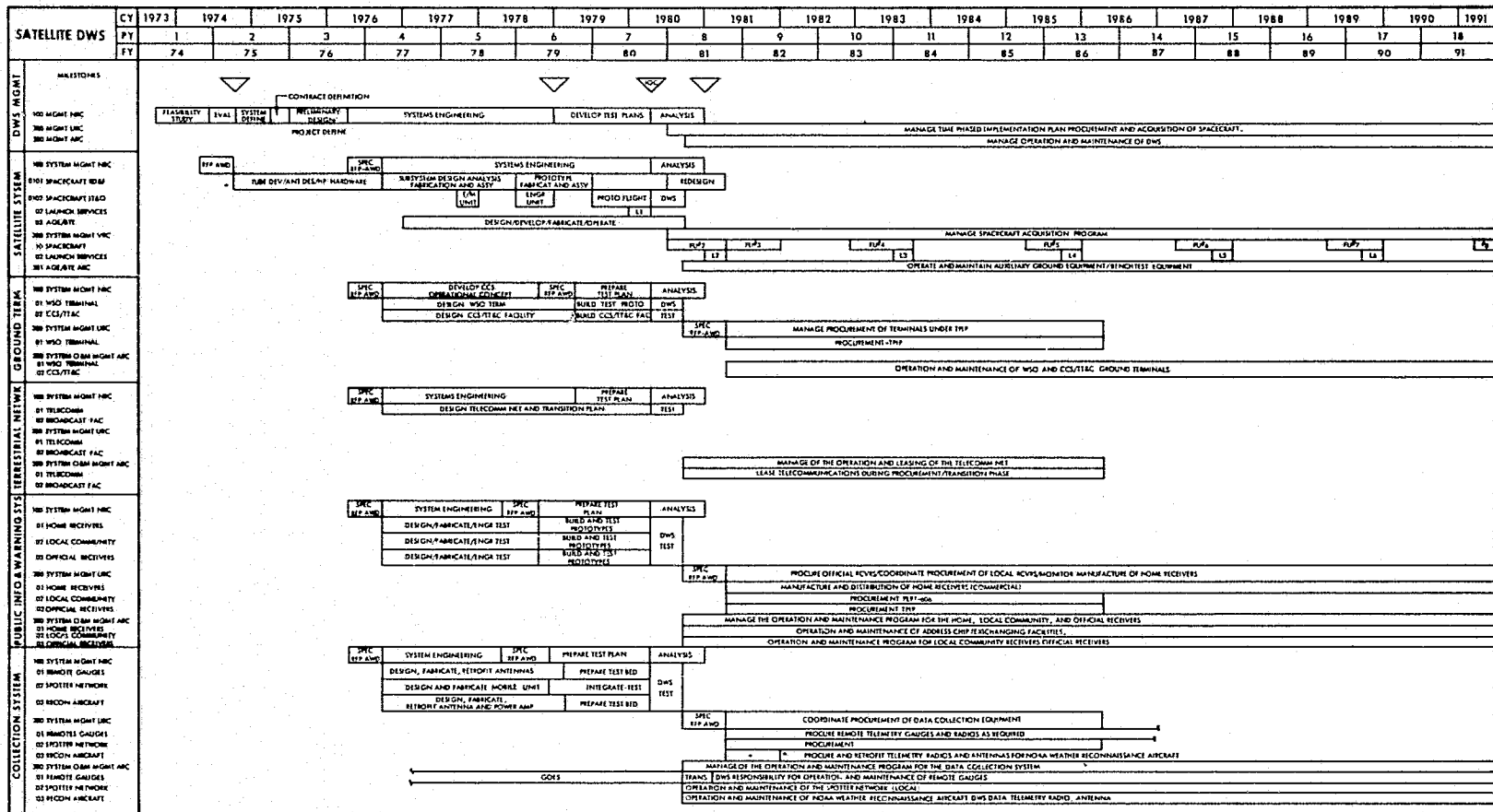


Figure 9-2. Satellite Disaster Warning System, Implementation Schedule

the major tasks for each of the component subsystems with respect to time sequence in which the tasks must be accomplished and clearly indicates the event interdependencies and critical events. The schedule also shows the project milestones and their relationships to the specific tasks.

9.3.2 Milestones/Decision Points

The first milestone is the decision point which will occur after the evaluation of the feasibility study of using satellites for a DWS. The evaluation will consider the proposed cost and the estimated risk for each of the feasible alternatives. The decision by NOAA will indicate the direction for the further DWS development. Assuming that the satellite DWS is selected, the second milestone is a decision point which will occur at the completion of the satellite engineering unit testing phase. This decision considers the program progress and the system potential. An evaluation will determine how well the project is attaining the system goals and objectives as well as meeting the time and funding schedule. The basic decision by NOAA at this point must consider the risk and feasibility of the prototype unit being completed within the estimated time and funding constraints as well as meeting the design requirements. At this time, any necessary changes in the system design which may affect the other DWS subsystems should be determined. The next milestone is the Initial Operational Capability (IOC) which will occur when the first DWS satellite is launched and becomes operational. The DWS will receive an operational test with a limited number of ground facilities in operation. The next milestone is the decision point which occurs at the completion of the DWS test when the test results have been analyzed. It is at this time that a decision will be made to commit resources for the development of all additional DWS facilities. This decision will consider how well the system meets the design requirements, time and funding constraints and changes recommended as a result of the system test and analysis. These changes may be in the form of equipment modifications or revisions in operational procedures and/or cost estimates based on the limited operational data and experience from the system test.

MTTF calculations are based on statistical analyses which can only be applied confidently to a large population of satellites. Each satellite launch (success or failure) and each satellite failure while in orbit will constitute a decision point with respect to the need to program additional satellites.

9.3.3 Implementation

Subsequent to the commitment of resources as a consequence of the last decision, the total DWS will be implemented over 5 years. This implementation will require recruiting and training of specialists, manufacture and installation of complicated electronic equipment, and a comprehensive program of education and planning in cooperation with Federal, State, and Community officials and the mass media. The implementation should be accomplished in four basic phases. The first phase would be to equip all 50 WSFOs with the satellite communications terminals

with the WSO linked by terrestrial land lines. Phase II would be to implement the DWS plan in the area known as "Tornado Alley" by installing the satellite communications terminals and the spotter network base units at the WSOs in the states of Alabama, Arkansas, Georgia, Illinois, Indiana, Iowa, Kansas, Louisiana, Michigan, Mississippi, Missouri, Ohio, Oklahoma, Texas, and Wisconsin. In Phase III, the DWS would be implemented in the peripheral remainder of the tornado area, remaining states (and Caribbean) in the hurricane area, the northeastern states, and the Pacific Northwest flooding areas as shown in Figure 9-3. Implementation of the DWS would be completed in Phase IV with inclusion of the southwestern conterminous United States, the intermountain region, Alaska, and Hawaii.

This geographic phasing of the DWS implementation is the same as that recommended in a proposed Nationwide Natural Disaster Warning System (NADWARN) prepared by NOAA (then ESSA) in October 1965.

9.3.4 Disaster Warning System Management

Overall management of the DWS is the responsibility of NOAA. The management activities at this level are primarily directed to the control and direction necessary to ensure meeting DWS requirements and to coordinating and interfacing management of the DWS subsystems. The management activities are divided into six major functional areas: mission analysis, systems engineering/integration, project planning and control, logistics support, production engineering, and project support services. These areas encompass the entire scope of work necessary to define, plan, and control the development, acquisition, and operation of the DWS.

In the initial phases of the program, management activities will relate to the RDT&E phase which is associated with nonrecurring costs. These costs are those primarily associated with the research and development of the DWS to a point at which the system has an IOC. This includes the basic engineering design, development, testing, and manufacture of the prototype system components to demonstrate that the developed system meets the DWS design requirements. It also includes the necessary tooling, test equipment, test hardware, ground equipment, facilities, and training to support the DWS through the completion of the RDT&E phase. Only the critical activities in the management functional areas are shown in Figure 9-2. The completion of the Feasibility Study and the evaluation are essential to the first decision point. Assuming that the satellite DWS is selected, the satellite system must be more fully refined to enable contract definition for the Preliminary Design/Project Definition Phase. Upon completion of this phase, the specifications and requests for proposals for the DWS subsystems will be prepared and contracts awarded for subsystem development. During the subsystem development, the DWS management will perform systems engineering/integration, develop test plans, analyze the test results, and in the other functional areas.

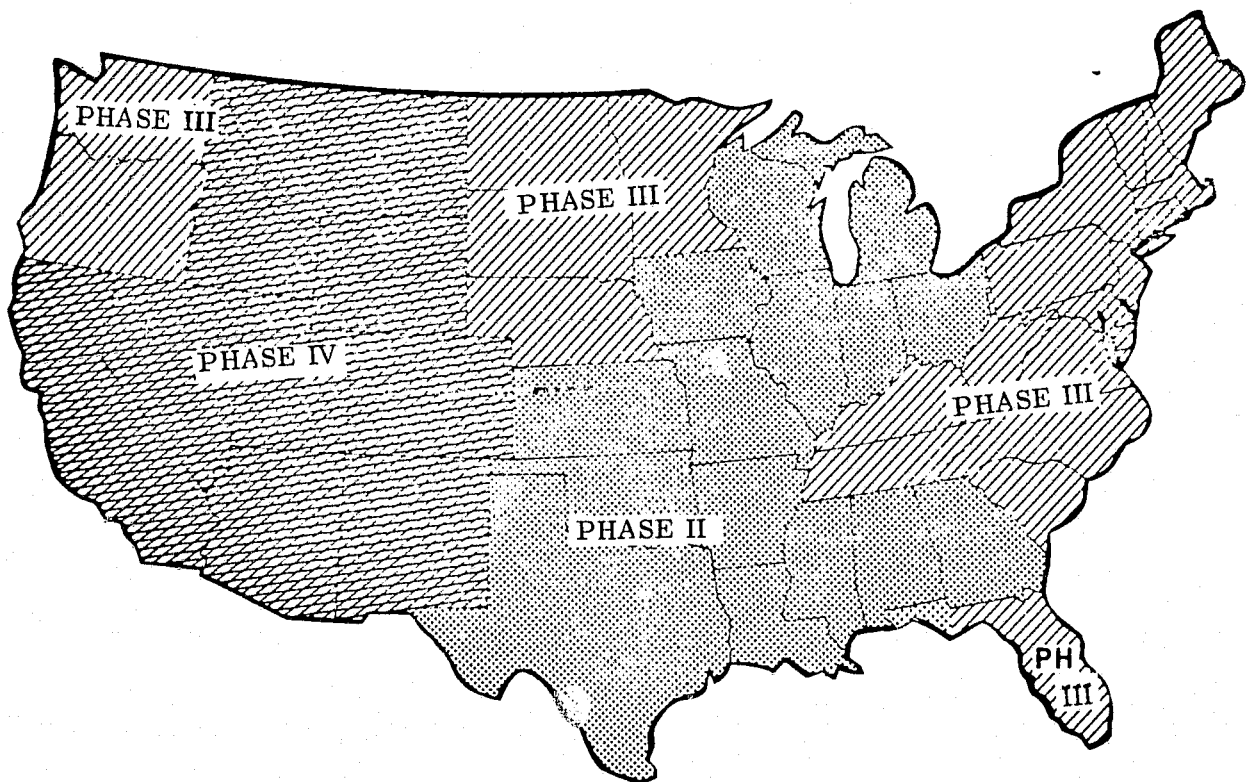


Figure 9-3. Phasing of Implementation

Subsequent to the development of the IOC, the DWS management activities will relate to the procurement of the DWS components in accordance with the provisions of the implementation plan. This procurement is associated with the unit recurring costs. These costs are those which are incurred by the acquisition of major equipment items, installation and testing, support facilities, initial spares and repair parts, and necessary test and maintenance equipment required to support the operations program. The management effort at this level will be primarily devoted to coordinating the procurement effort between the DWS subsystems and the allocation of resources to accomplish the time-phased implementation plan. The acquisition of spacecraft and launch services will be accomplished on a periodic basis. While the spacecraft procurement will be managed by the satellite system management (NASA), the overall acquisition responsibility rests with DWS management (NOAA).

Following the acquisition of the DWS equipment and facilities, the DWS management activities will relate to the operation and maintenance of the DWS. The operation and maintenance is associated with the annual recurring costs. These costs are those incurred after the acceptance of the DWS equipment and facilities. At the subsystem levels, these costs will be of three types; operations, maintenance, and communications for leased communications facilities. At the DWS management level, the annual recurring costs will be those associated with financing, training program, system test and evaluation, technical management and engineering, system control, and administrative services.

9.3.5 Satellite System

The management of this DWS subsystem will be the responsibility of NASA. One of the functions of NASA will be to define the interface between the satellite system and the other DWS component systems. As previously stated, technology work will be required in high powered hardware, multiplexing equipment, and amplifier tubes, as well as the design and deployment of a large spacecraft antenna for downlink transmissions. These items require a relatively long lead time for development and contracts should be prepared and awarded as quickly as possible for the development of high powered amplifier tubes with a high reliability, the design of the large antennas required, and the technological development for other necessary hardware.

Following the Preliminary Design/Project Definition Phase, specifications will be developed for an RFP for the design, development, fabrication, integration, testing, and qualification of the satellite launch vehicle/shuttle integration, mockup, dynamic thermal/mechanical test unit, engineering test unit, and protoflight satellite. The contract will also cover the design, development, and fabrication of the necessary satellite auxiliary ground equipment/bench test equipment. Subsequent to the development and operation of this equipment in the RDT&E phase, it will be associated with the operation and maintenance phase and used to assist in the procurement of subsequent spacecraft.

Subsequent to the launch of the protoflight unit, the DWS will be tested. The analysis of the test results may impact on any or all DWS subsystems and cause some redesign of components to improve system effectiveness, component efficiency, and to reduce cost. Shortly after the DWS test is initiated, the construction of Flight Unit No. 2 can commence. It is estimated that the fabrication, integration, testing, and qualification of the production models can be accomplished in 9 months. The construction schedule for Flight Unit No. 2 must be flexible enough to accommodate minor changes which may result from the analysis of the DWS test results. Flight Unit No. 3 will be fabricated immediately following Flight Unit No. 2 in order to provide a spare satellite in event of a launch failure. In actual practice, it may be possible to have some overlap in the fabrication without increasing the production facilities. The production of the subsequent flight units will be scheduled to conform to the launch strategy resulting from the required satellite system reliability.

Assuming that satellites and launch vehicles are in storage, approximately 3 to 6 months' advance notice is required to launch and place satellites in operational use under normal conditions.

Ideally, one in-orbit spare should be maintained for each operational satellite. However, the cost of this strategy would most likely be unacceptable. In this respect, experience with monitoring the health of communications satellites indicates that failures due to degradation of components can be predicted several months in advance.

9.3.6 Ground Terminals

The management of the ground terminal system will be the responsibility of NOAA. Subsequent to the Preliminary Design/Project Definition Phase at the DWS management level, specifications and an RFP must be developed by the ground terminal management for the design of the satellite WSO terminals, central control station (CCS), tracking telemetry, and command (TT&C) terminal. Concurrently, with the design of these terminals, the CCS operation concept must be developed. These design and development tasks are dependent on the results of the DWS Preliminary Design/Project Definition Phase. Based on the information available, it does not appear that the design of the WSO terminals and/or CCS-TT&C terminals are on the critical path in the implementation of the DWS and that the time shown on the schedule for this task may exceed the actual time required for the task. Subsequent to the completion of the terminal designs, specifications for an RFP must be developed for the construction of the terminals and the fabrication, installation, and testing of the terminal equipment. Concurrently, a test plan must be prepared which will be conducted after launch of the protoflight spacecraft. It is anticipated that at least three WSO terminals in addition to the CCS-TT&C terminal will have to be procured in the RDT&E phase for the DWS test.

If the decision at the conclusion of the engineering tests was to conclude a fairly high degree of risk in the development of a satisfactory prototype unit, the minimum number of prototype terminals should be built for the DWS system test. If, however,

the conclusion is that there is a low risk, additional units should be procured by advancing the 5-year acquisition plan. In this manner, greater benefits from the useful life of the protoflight satellite can be realized.

Subsequent to the DWS test and analysis of the test results, an RFP for the acquisition of the remaining WSO terminals will be prepared. The specifications will reflect any changes necessary as a result of the DWS test analysis. Acquisition of the remaining terminals will be made in accordance with the priorities established in the time-phased implementation plan. As the ground terminals are procured, the annual operating costs for the operation and maintenance will be increased. These costs are operations, maintenance, and communications. Operations costs include the cost of command and data acquisition, data processing analysis, technical management and engineering, and field stations operations such as rent, utilities, transportation, expendable supplies, and operations personnel. Maintenance costs include labor and materials for both facilities and equipment maintenance. Communications costs are the periodic, usually monthly, mileage, connection, terminations, and local loop charges for leased communications facilities necessary to access the communications and TT&C terminals.

9.3.7 Terrestrial Networks

Management of the terrestrial network will be the responsibility of NOAA. During the RDT&E phase of DWS, management of the terrestrial network will be primarily directed to the design of the telecommunications network necessary to support the DWS and the transition from leased circuits to satellite communications as the number of satellite WSO terminals increases to the design goal in accordance with the time-phased implementation plan. In addition, test plans must be prepared and results of the DWS test recorded and analyzed. The terrestrial network will not incur procurement costs and the annual operating costs will be the telecommunications leasing costs for the terrestrial network during the procurement period and the transition to the all-satellite communications system.

9.3.8 Public Information and Warning System

Management of the Public Information and Warning System will be the responsibility of NOAA. Specifications and the RFP will be prepared for the design, development, and fabrication of the engineering test models for the family of DWS receivers subsequent to the completion of the Preliminary Design/Project Definition Phase. This family will include not only the home receivers, but also the local community and official receivers as well. The engineering tests on this family of receivers should be completed as early as possible since the success of the DWS depends upon the verification that the receivers can be built to meet the design specifications and remain within the cost constraints. If the design specifications cannot be met, it will be necessary to re-examine the satellite transponder specifications. Upon satisfactory completion of the satellite and the Public Information and Warning System family of receivers, specifications and RFPs must be prepared for the manufacture and test of

the prototype receivers. Test plans will be prepared to determine the effectiveness of the demonstration DWS system. The test results will be analyzed to determine necessary changes in the specifications and RFPs for the large scale procurement of this family of receivers. The Public Information and Warning System management will be responsible for procuring the official receivers, coordinating the procurement of the local community receivers under the provisions of PL 91-606, and monitoring the manufacturing and distribution of the home receivers. The manufacture and distribution of the home receivers will be accomplished by commercial companies engaged in the manufacture and distribution of home entertainment electronics equipment.

The Public Information and Warning System management will also be responsible for the operation and maintenance program for the home, local community, and official receivers. The management organization for accomplishing this responsibility must be structured to accommodate the diversity of program recipients and the variety and types of equipment involved. One part of the organization will be responsible for administering the operation and maintenance of the federally owned and operated official receivers. Another part of the organization may have responsibility for coordinating operation and maintenance of the local community receivers and the dispersal of funds under the provisions of PL 91-606. Another part of the organization will have the responsibility for the operation and maintenance of any necessary facilities and inventories of parts for the exchanging and/or changing of the address chips which are required when the home receivers are moved from one addressable area to another. This part of the organization may also be required to monitor the servicing practices and procedures of the home receivers by commercial electronic equipment repair establishments.

9.3.9 Collection System

The management of the collection system will also be the responsibility of NOAA. One of the results of the Preliminary Design/Project Definition Phase will be the information necessary for the specifications and RFPs for the design, fabrication, and engineering test for each of the collection system component subsystems, remote gauges, spotter network, and reconnaissance aircraft. Again, it is necessary that these engineering tests be completed as early as possible to verify that design specifications can be met and remain within cost constraints. This is of particular importance for the spotter network mobile units because of the large number of items which must be procured. RDT&E costs for the remote gauge subsystem may result from the requirement to design, fabricate, test, and perhaps retrofit the communications equipment on the remote gauges. The degree of this will depend on how much of the GOES system characteristics can be retained in the DWS. Development cost for the reconnaissance aircraft subsystem will basically be limited to the design, fabrication, test, and retrofit of the antenna and the power amplifier for the aircraft-satellite link. For the spotter network subsystem, the mobile vehicular mounted/carried unit which the spotter will use to communicate with the WSO terminal must be completely designed,

fabricated, and tested. Subsequent to the satisfactory completion of design and tests of the engineering units, specifications and an RFP will have to be prepared for the acquisition of prototype demonstration units to be used in the DWS test. The spotter network will require several mobile units for each WSO terminal in the system model test. At least one of the NOAA weather reconnaissance aircraft will be equipped and retrofitted with the satellite radios and antennas. The exact number of remote gauges to be involved in the test will depend on both the GOES program and the scheduled procurement and installation of remote gauges.

Following the DWS test and the analysis of the test results, the collection system management will be responsible for coordinating the procurement of the collection system equipment. Specifications and RFPs must be prepared for procurement and retrofit of the radios and antennas for the remaining NOAA Weather Reconnaissance Aircraft, and of radio sets and antennas for the existing remote gauges not under the GOES program. Specifications will be prepared for procurement of the spotter network mobile units.

The collection system management will also have the responsibility for the operation and maintenance of the DWS collection system. The conversion of the remote gauges from operation under the GOES program to operation under DWS must be fully coordinated to ensure uninterrupted acquisition of data from remote gauges. The collection system management will also be responsible for managing the operation and maintenance of the NOAA weather reconnaissance aircraft DWS radios and antennas.

9.4 Time-Phased Funding Plan

The time-phased funding plan is based on the estimated costs for each of the component and subcomponent systems as developed in Paragraph 8.5.1 for the baseline satellite DWS and Paragraph 8.5.2 for the baseline terrestrial DWS.

The time-phased costs by project year for the terrestrial DWS are shown in Table 9-1. Figure 9-4 portrays a graphic representation of funding by category, non-recurring, unit recurring, and annual recurring as well as total cost. The numbers in parentheses represent the total cost for each category. It is assumed that 2 years will be required for the necessary R&D to develop the home broadcast receiver system. Subsequent to the development of these receivers the balance of the DWS will be procured over a 5-year period.

The time-phased costs by project year for the satellite DWS are shown in Table 9-2. Figure 9-5 portrays a graphic representation of funding by category. Again, the numbers in parentheses represent the total estimated cost for each category. The length of time for the various elements of the work breakdown structure are estimated from the development history of similar type satellites. The amount of R&D funds allocated to the project years are based on the number of equivalent units that each step is allocated from the tabulation of equivalent units in Table 8-1. The cost of

Table 9-1. Funding Schedule, Baseline Terrestrial System

	PY FY	1 74	2 75	3 76	4 77	5 78	6 79	7 80	8 81	9 82	10 83	11 84	12 85	13 86	NRC	URC	ARC	Total
Terrestrial Networks																		
Telecommunications ARC					14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4			144.0	144.0
Broadcast Facilities URC					5.68	5.68	5.68	5.68	5.68							28.4		374.9
ARC					8.66	17.34	26.00	34.70	43.3	43.3	43.3	43.3	43.3	43.3			346.5	
Public Info & Warn Syst NRC			1.25	1.25											2.5			2.7
URC					0.1											0.1		
ARC					0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01			0.1	
Collection System																		
DCP URC					12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5		125.0		156.2
ARC					2.58	3.76	4.94	6.12	7.3	7.3	7.3	7.3	7.3	7.3			61.2	
Spotter URC					41.48	41.48	41.48	41.48	41.48							207.4		297.2
ARC					4.42	5.94	7.46	8.98	10.5	10.5	10.5	10.5	10.5	10.5			89.8	
Baseline System Total NRC			1.25	1.25											2.5			
URC					59.76	59.66	59.66	59.66	59.66	12.5	12.5	12.5	12.5	12.5		360.9		
ARC					30.07	41.45	52.81	64.21	75.51	75.51	75.51	75.51	75.51	75.51			641.6	
Total			1.25	1.25	89.83	101.11	112.47	123.87	135.17	88.01	88.01	88.01	88.01	88.01				1,095.0

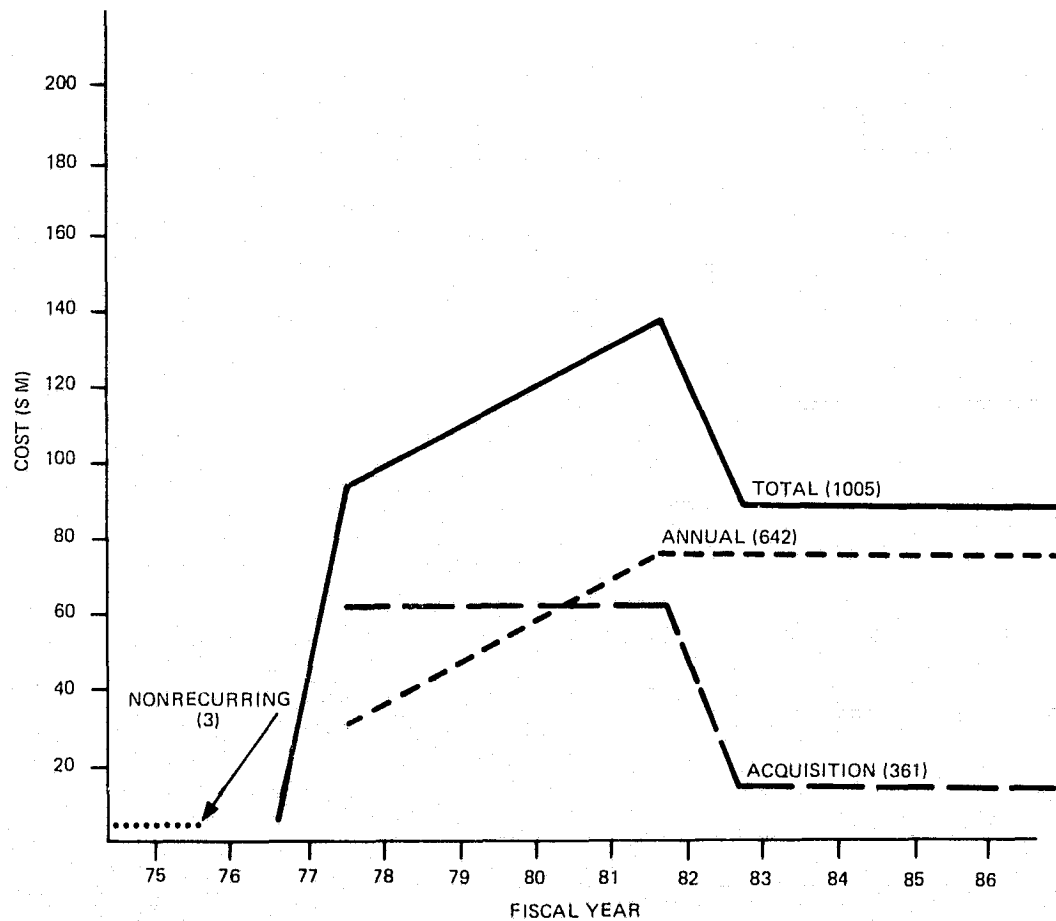


Figure 9-4. Baseline Terrestrial Funding Schedule (74\$)

Table 9-2. Funding Schedule, Baseline Satellite System

	PY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Salv	NRC	URC	ARC	Total
	FY	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91					
Satellite																								
Spacecraft NRC			11.54	11.54	96.29	84.75	86.53	13.85	16.80											128.8	321.3			596.4
URC									57.7	57.7	57.7		57.7		57.7		57.7		57.7			403.9		
Launch																								
Service NRC								13.3												16.4	13.3			76.7
URC									13.3	1.33	1.33	14.63	1.33	14.63	1.33	14.63	1.33	14.63	1.33			79.8		
AGE NRC					4.66	4.66	1.33	1.33	1.33															26.6
ARC										1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33				13.3	
Ground Terminals																								
WSO NRC					0.7	0.7	0.7	0.2	0.2												2.5			52.6
URC										6.34	6.34	6.34	6.34	6.34								31.7		
ARC										.46	.92	1.38	1.84	2.3	2.3	2.3	2.3	2.3	2.3				18.4	
CCS NRC					0.5	0.7	0.7	2.0	1.5												5.4			20.8
ARC										1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54				15.4	
Public Info &																								
Warn Syst NRC					1.0	1.0	0.3	0.2													2.5			2.7
URC									0.1													0.1		
ARC									0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01				0.1	
Collection System																								
DCP NRC					0.1	0.1	0.1	0.1													0.4			172.6
URC									5.0	7.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5					
ARC									.47	.71	2.36	3.54	4.72	5.9	5.9	5.9	5.9	5.9	5.9				125.0	
Spotter NRC					1.0	1.0	0.3	0.1	0.1															
URC										100.68	100.68	100.68	100.68	100.68										
ARC										4.02	8.04	12.06	16.08	20.1	20.1	20.1	20.1	20.1	20.1				503.4	
Baseline System																								
Total NRC			11.54	11.54	104.25	92.91	89.96	31.08	19.93											145.2	361.2			1615.1
URC									76.1	173.55	178.55	184.15	178.55	134.15	71.53	27.13	71.53	27.13	71.53					
ARC									.48	8.07	14.20	19.86	25.52	31.18	31.18	31.18	31.18	31.18	31.18				1143.9	
TOTAL			11.54	11.54	104.25	92.91	89.96	31.08	96.51	181.62	192.75	154.01	204.07	165.33	102.71	58.31	102.71	58.31	102.71				255.2	1615.1

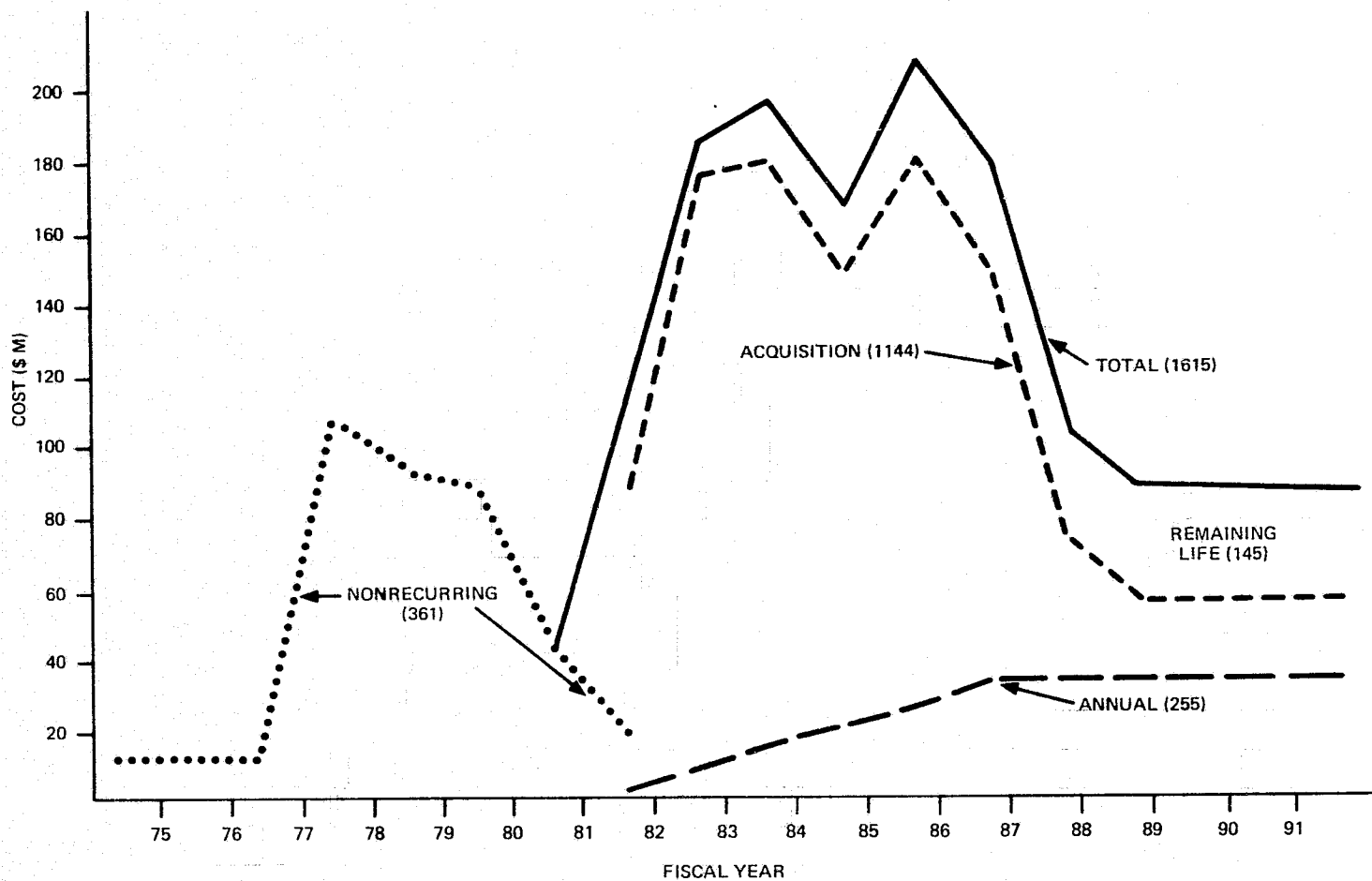


Figure 9-5. Baseline Satellite Funding Schedule (74\$)

a flight unit expended on an unsuccessful launch will be accounted for by always having a spare on hand, while the cost of the expected launch failure is prorated over the 10-year period. The satellite launch schedule maintains a minimum system reliability such that there is a useful space system life remaining after 10 years. This useful life is equivalent to the salvage value of the system and is subtracted from the total system cost to arrive at the 10-year life cost.

Based on the funding schedule, it is now possible to compute the uniform equivalent annual cost over the expected payoff period. Table 9-3 shows the present worth values for each baseline system discounted at an annual interest rate of 10 percent. The equivalent uniform annual rate for each of the systems over the payoff period is determined as follows:

- Baseline Terrestrial System: Payoff period project years 4-13 inclusive. Present worth of system is computed and then future worth in constant 1974 dollars is determined before using the capital recovery factor to determine the Uniform Annual Cost (UAC).
$$\text{UAC} = \$519.05\text{M} \times 1.21 \times 0.16275 = \$102.22\text{M}$$
- Baseline Satellite System: Payoff period, project years 9-18 inclusive.
$$\text{UAC} = \$708.78\text{M} \times 1.9487 \times 0.16275 = \$224.79\text{M}.$$

Table 9-3. System Present Worth

PY	Baseline Terrestrial System			Baseline Satellite System			
	Total Annual Budget	10% Pwf	Discounted Annual Cost	PY	Total Annual Budget	10% Pwf	Discounted Annual Cost
1	1.25	0.9091	1.14	1	11.54	0.9091	10.49
2	1.25	0.8264	1.03	2	11.54	0.8264	9.54
3	89.83	0.7513	67.49	3	104.25	0.7513	78.32
4	101.11	0.6830	69.06	4	92.91	0.6830	63.46
5	112.47	0.6209	69.83	5	89.96	0.6209	55.86
6	123.87	0.5645	69.92	6	31.08	0.5645	17.54
7	135.17	0.5132	69.37	7	96.51	0.5132	49.53
8	88.01	0.4665	41.06	8	181.62	0.4665	84.73
9	88.01	0.4241	37.33	9	192.75	0.4241	81.75
10	88.01	0.3855	33.93	10	154.01	0.3855	59.37
11	88.01	0.3505	30.85	11	204.07	0.3505	71.53
12	88.01	0.3186	28.04	12	165.33	0.3186	52.67
	1005.0		519.05	13	102.71	0.2897	29.76
				14	58.31	0.2633	15.35
				15	102.71	0.2394	24.59
				16	58.31	0.2176	12.69
				17	102.71	0.1978	20.32
				Salv	145.2	0.1978	28.72
				Total	1615.		708.78

SECTION 10 - DISCUSSION OF RESULTS AND CONCLUSIONS

Both the terrestrial and satellite baseline systems essentially satisfy the NOAA DWS requirements. The exceptions are: the terrestrial system does not provide ocean coverage, and the satellite system provides only 5 rather than 50 simultaneous voice channels to the spotters.

The comparative performance of the terrestrial and satellite systems can be summarized according to the four functional requirements; disaster warnings, spotter reports, data collection and coordination.

Disaster warning with the satellite system provides broad coverage but is capacity-limited with substantial cost savings resulting as the number of required simultaneous transmissions are reduced. The terrestrial system can provide an overall high capacity since it consists of a large number of independent transmitters each capable of sending two simultaneous messages. However, the terrestrial system is coverage-limited so that as coverage increases from 90 to 99 percent of the population, more than twice as many transmitters are required.

The spotter reporting costs for both systems are strongly driven by the large number (100,000) of spotters. The satellite system requires a more sophisticated transceiver and the resulting costs are higher. The satellite system is thus impacted more adversely than the terrestrial system with a large number of spotters.

The last two functions are a small percentage of the total system cost. The data collection function is ideally suited to a satellite system. The terrestrial data collection system is slightly more expensive and has a slower response time since a rather extensive terrestrial network is required to connect the WSOs to the points where the data is collected. Much of this data would be collected using a satellite system such as the present GOES. No costs are charged against the terrestrial system for such a satellite data collection capability.

The coordination function can be relatively easily implemented by a satellite as long as the capacity does not greatly exceed the required 10 duplex channels. The costs to provide the coordination function with a terrestrial system are approximately an order of magnitude greater than that required with a satellite system. However, the terrestrial cost for the coordination function is small compared to the total system costs. The terrestrial system has a greater capacity capability but is somewhat coverage limited.

The total system cost, including 10 years of operation, is high for both systems; the baseline terrestrial system cost is \$1.00 B and the baseline satellite system cost is \$1.62 B in constant 1974 dollars. The home receiver costs are not included; their unit factory costs are \$17.60 and \$31.20 in quantities of one million for the terrestrial and satellite systems, respectively. Their cost differences are primarily a function of the

number of channels required to be received; two in the terrestrial system and 10 in the satellite system. If the number of simultaneous warning channels were to be reduced from 10 to 4, for example, the receiver cost for the satellite system would be accordingly reduced.

Of the four DWS functional requirements (disaster warning, spotter reporting, data collection and coordination), the costs of both baseline systems are dominated by the disaster warning and spotter reporting functions; 67 and 89 percent for the terrestrial and satellite systems, respectively. The dominance of the disaster warning function is understandable, particularly for the satellite, since broadcasts must be received directly by inexpensive home receivers. However, the cost magnitude of the spotter reporting function was not anticipated. As noted earlier, this large cost is caused primarily by the large number (100,000) of transceivers that must be purchased and maintained for ten years.

Noting the cost drivers, an effort was undertaken to reduce system cost through lower capability, alternative systems. These were generated by modifying the baseline systems.

The DWS satellite requirement for disaster warnings called for at least 10 simultaneous channels. This requirement, being the most significant cost driver of the satellite was reduced to four in some alternative cases. Based upon the estimated warning traffic for 1985 and a standard queueing model, with four channels the probability of a warning message being delayed more than one minute is about 6×10^{-5} , i. e., about one message/month would experience a delay of 1 minute or greater. With a message priority system this could be significantly improved upon.

The costs of different satellite system alternatives ranged from \$1.32 B to \$0.87 B for a reduced number of warning channels and different spotter reporting approaches. The different spotter reporting techniques used included a digital capability instead of voice and a replacement of the satellite spotter implementation with the terrestrial spotter technique. A satellite having a weight of about 1140 kg (2500 pounds) and an array BOL power approaching 2 kW appears feasible for these reduced requirements. A terrestrial alternative with the coverage reduced to an estimated 95 percent of the population was considered and this reduced the total terrestrial system cost to \$0.84 B.

A hybrid DWS was also developed. For this system, the satellite relays disaster warnings to terrestrial broadcasting facilities. The estimated system cost for this hybrid is \$1.44 B. However, this system was developed with the primary goal of reducing the satellite cost. Total system cost may be reduced by optimizing the hybrid system with respect to the total system cost rather than just the satellite cost. However, in view of the fact that the hybrid system essentially retains all of the cost of the terrestrial system, while adding the cost of the satellite and additional ground terminals, it does not appear that it could be more cost effective than either a fully optimized terrestrial or satellite DWS.

One final distinction between the terrestrial and satellite systems should be made. The terrestrial system tends to be more labor intensive than the satellite system which accounts for a significant portion of its annual recurring costs. This assumes one around-the-clock technician for every 2.5 VHF broadcasting facilities. This reflects itself in the total annual cost for the terrestrial system during the operations phase being approximately the same as the satellite system where the primary cost is due to replacement satellites.

It is apparent that additional study of both the terrestrial and satellite systems is required to develop optimal configurations and more detailed system definitions on which to base a final system choice. The DWS requirements should also be assessed in view of the cost sensitivities to some of the requirements developed in this study.

Finally, since the DWS capacity is sized to handle peak loads, the communication capacity utilization is low (about 15 percent). It may be possible to share this capacity with non-critical traffic within the NWS as well as with other noninterfering agencies' traffic using priority techniques to ensure that DWS traffic is not delayed. If costs are shared with other operations within the NWS or with other agencies, the cost of disaster warning could be reduced.